Technical Report:

Refinement of WARMF For the TMDL Calculations in the Lower Catawba River Watershed In South Carolina

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1. INTRODUCTION

The WARMF model has been applied to the Catawba River Basin that extends from the headwaters of Lake James in North Carolina to Lake Wateree in South Carolina. The model for the entire system has been calibrated for the time period of 1992 to 1996.

Drs. Hank McKellar and Daniel Tufford of the University of South Carolina (USC) received an EPA 319 grant to develop TMDLs for streams and reservoirs in the Lower Catawba River System. With this grant, they collected stream water quality data for sub watershed tributary to Fishing Creek Reservoir. Systech Engineering, Inc. was subcontracted to extend the database to year 2001 and to calibrate the model with the new observed data and available water quality data of the Lower Catawba River from Lake Wylie to Lake Wateree. The report for the modeling work was submitted in early 2002 (Systech 2002).

During a watershed group meeting, stakeholders raised concerns regarding the quality of some data used to calibrate the model. Details of questioned data are discussed in Chapter 2. It was suggested to remove or modify those questioned data and to recalibrate the model anew. This report is prepared to document the results of such effort.

Since the release of the original calibration report (Systech 2002), WARMF has been upgraded to model BOD as a separate water quality parameter rather than as a part of dissolved organic carbon, which is supposed to represent long chain organic acids from the decay of organic matter in land catchments. Algorithms in the model related to phosphorous adsorption to sediment and algae in lakes were also made more flexible by giving related parameters more spatial variation. This report documents the result of these modifications.

2. DATA REVISIONS

Data used to calibrate the WARMF model are compiled from a variety of sources. Typically these sources include databases maintained by state and federal agencies such as USGS or state environmental protection agencies. Published data from these agencies usually undergo quality assurance/quality control measures to ensure accuracy. It is not uncommon, however, that errors are later found in the data and that revisions are made. This was the case with some of the data used during the original round of calibration for the Lower Catawba River Watershed study. The questioned data are 1) the stream water quality data collected by USC in the Fishing Creek Region; 2) the point source data for a discharger on the Catawba River above Fishing Creek Reservoir; and 3) the monitoring data at water quality stations maintained by the South Carolina Department of Health and Environmental Control (SCDHEC).

USC DATA ON FISHING CREEK

The data, collected by the University of South Carolina (USC) in Fishing Creek, was deemed inappropriate for use in model calibration. Table 2-1 is a list of the USC stations from which data was removed, and Figure 2-1 shows the location these stations.

In place of the USC data, the water quality data collected by the Analytical Laboratory of Duke Energy Company was added to the observed water quality file of Fishing Creek. The station is Fishing Creek at County Road 347 (FishCr347.orc), which is same as the USC Station 5. The data was collected in November 9 and 10, 2000, during which there were storm water runoff. Therefore the data includes measurements of ammonia, nitrate, total nitrogen, ortho-phosphate, and total phosphate, resulting from some nonpoint source loads of tributary watershed.

Table 2-1
Data stations at which USC data was removed

No.	File name	USC station ID	Description
1	FishBr.orc	49	Fishing Br at SC 49
2	FishCr161.orc	161	Fishing Cr u/s of Res. SC 161
3	LanghamBr.orc	LB	Langham Branch at SC #5 in City of York
4	FishCr1172.orc	1172	Fishing Cr at Co Rd 1172
5	FishCr347.orc	347	Fishing Cr at Co Rd 347
6	FishCr3.orc	RR	Fishing Cr at S-46-503

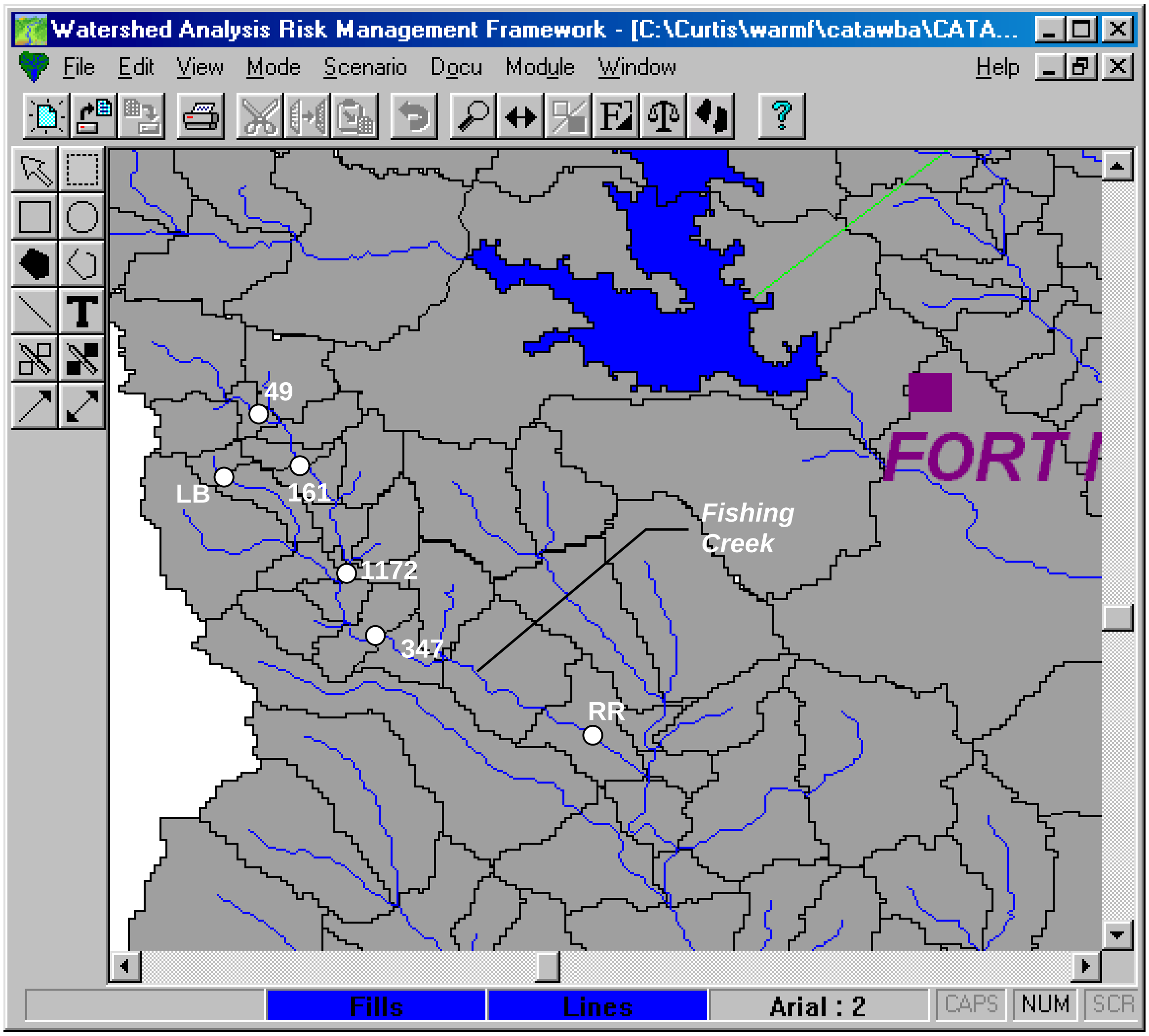


Figure 2-1
Location of University of South Carolina water quality sampling stations.

BOWATER POINT SOURCE DATA

The point source data of Bowater Inc. retrieved from the EPA PCS was found to have errors. Flow and dissolved oxygen (DO) data were corrected for the period from February 1999 to April 2001. The revised point source file in WARMF is "SC0001015.pts." Figure 2-2 shows the location of Bowater point source discharge, i.e. on the Catawba River downstream of the confluence of Twelve Mile Creek.

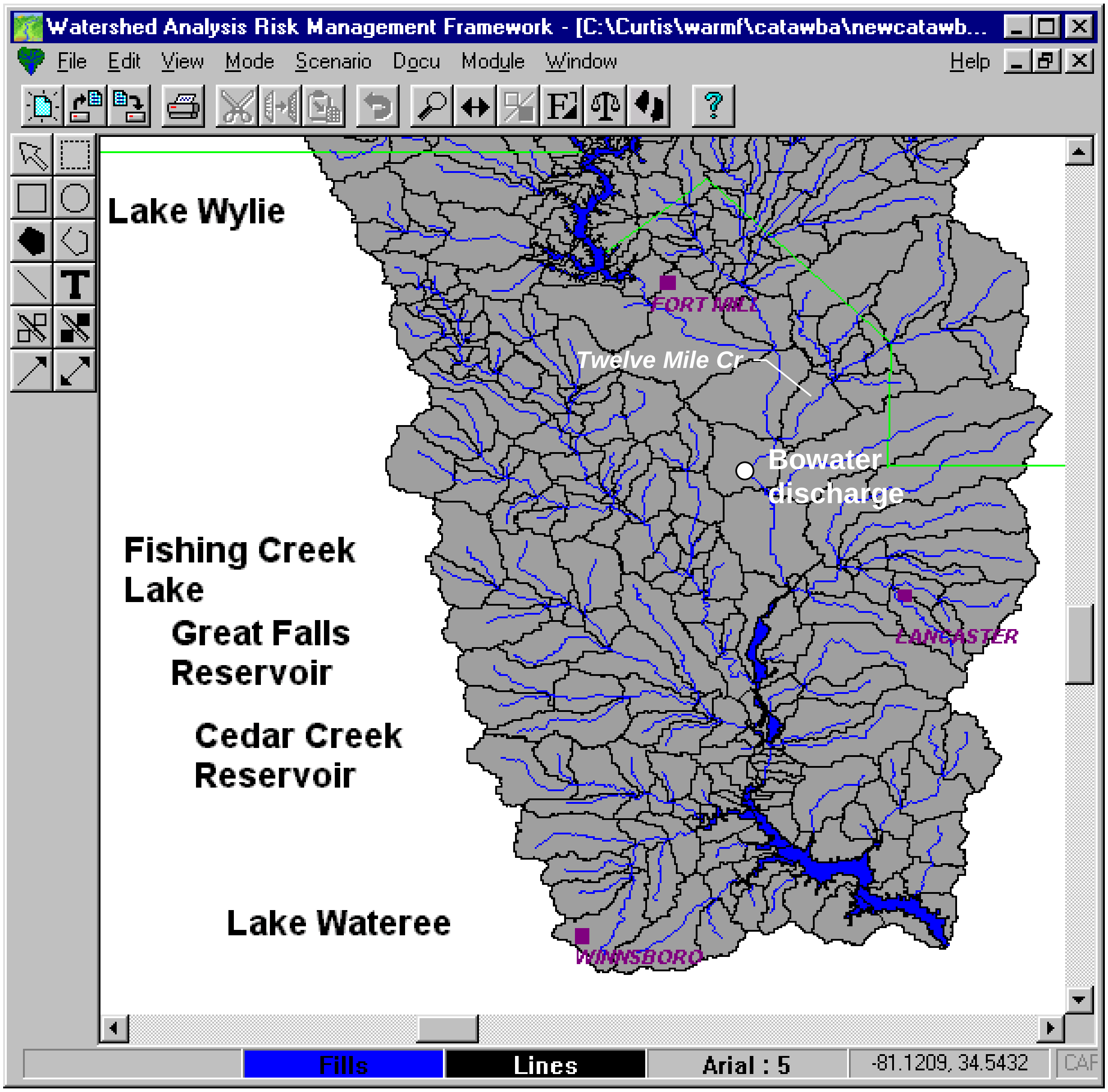


Figure 2-2
Location of Bowater point source discharge.

SCDHEC PHOSPHOROUS DATA

The concentrations of nutrients are routinely measured in South Carolina Surface Water Quality Monitoring Program (SCDHEC 2002). Total phosphorous (TP) and other nutrient are measured at more than 60 locations within the Catawba River Basin (Figure 2-3). Data stations are in red triangles. The stations relevant to this study are red triangles inside the watershed boundary shown in thick black line.

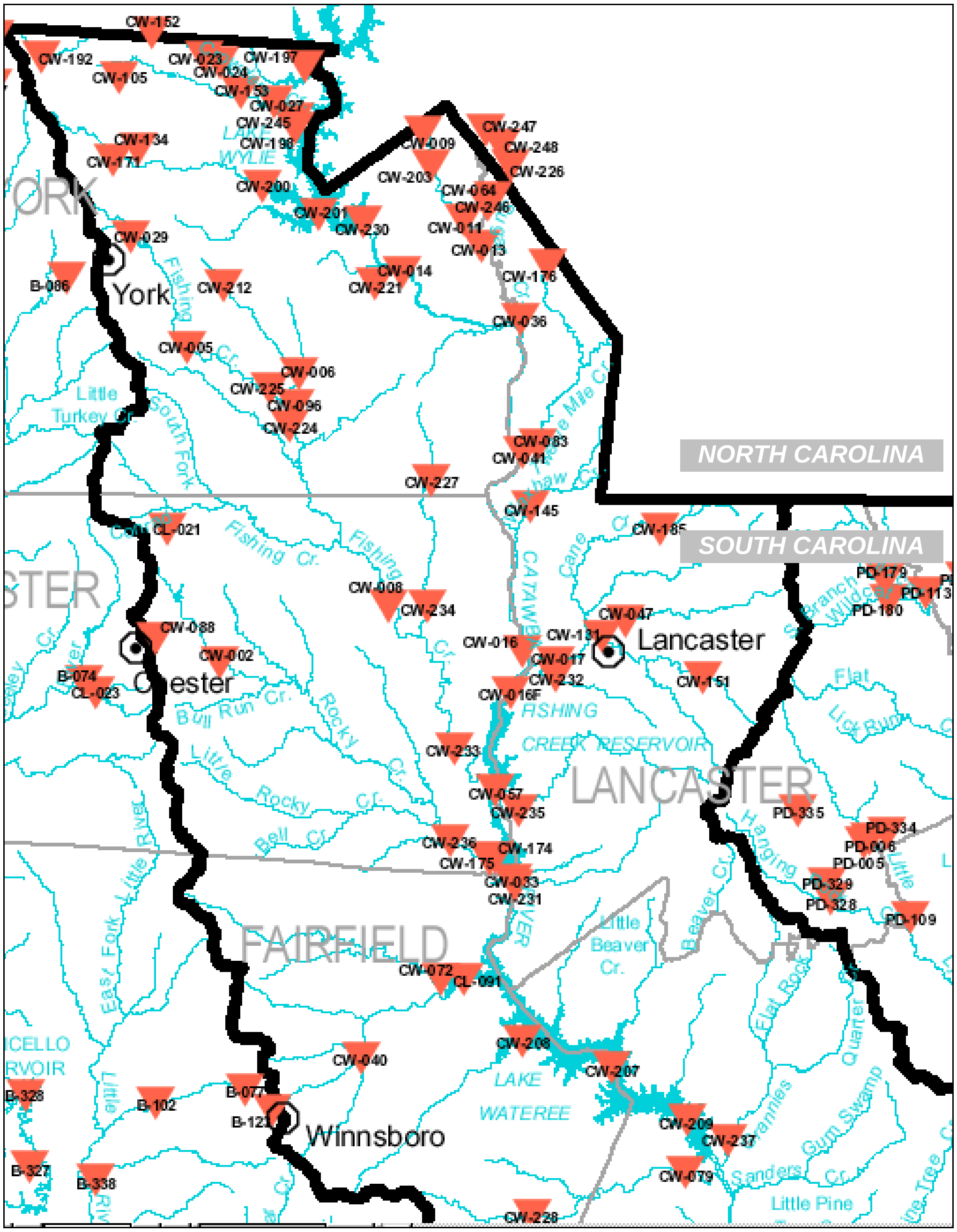


Figure 2-3
Locations of SC DHEC surface water quality monitoring stations.

The SCDHEC has found errors in the TP measurements from July 1998 to December 2001. These data have been deleted from the WARMF database. Data for other period remain in the database.

Table 2-2 shows the sampling stations where TP data have been removed. Several other stations have SC DHEC data, free of TP error. Also SC DHEC maintains some stations in North Carolina, e.g. “LITSUG.ORC” (CW-593), “SUGAR1.ORC” (CW-592).

Table 2-2
SCDHEC stations at which TP data was removed.

No.	File name	SC DHEC station	Description
1	ABVWAT.ORC	CW-231	Catawba R approx. 50 yds d/s of Cedar Cr
2	ALLISON.ORC	CW-171	Allison Cr at US-321, 3.1 mi S of Clover
3	BEAR.ORC	CW-151	Bear Cr at S-29-362, 3.5 mi SE of Lancaster
4	BEAR2.ORC	CW-131	Bear Cr at S-29-292 1.6 Mi W of Lancaster
5	BEAVERDAM.ORC	CW-153	Beaver Dam Cr At S-91-152, 8 mi. E of Clover
6	CALABASH.ORC	CW-134	Calabash Br at S-91-414, 2.5 SE of Clover
7	CAMP.ORC	CW-235	Camp Cr at SC 97
8	CANE.ORC	CW-017	Cane Cr on County Rd 50 near Irwin Farm
9	CANE2.ORC	CW-185	Cane Cr at SC-200, 5 mi. N-NE of Lancaster
10	CATABVFC.ORC	CW-041	Catawba R at SC 5, above Bowater Corp. effluent
11	CATBELWY.ORC	CW-014	Catawba R at US 21
12	CROWDER.ORC	CW-023	Crowders Cr at Ridge Rd near Bowling Green
13	CROWDER2.ORC	CW-152	Crowders Cr at US 321, 0.5 mi N of NC border
14	CROWDER3.ORC	CW-192	Crowders Cr at S-91-79, 4.5 mi NW of Clover
15	FISHBR.ORC	CW-029	Fishing Br at SC 49
16	FISHCR1.ORC	CW-008	Fishing Cr at SC 223 NE of Richburg
17	FISHCR2.OLC	CW-057	Fishing Cr Reservoir 75 ft above dam
18	FISHCR2.ORC	CW-224	Fishing Cr at S-46-163
19	FISHCR3.ORC	CW-225	Fishing Cr at S-46-503
20	FISHCR4.ORC	CW-233	Fishing Cr at S-12-77
21	GILLS.ORC	CW-047	Gills Cr at Unimpr. Rd S-29-56 N-NW of Lancaster
22	GRASSY.ORC	CW-088	Grassy Rn Br on SC 72, 5 mi. S-SW of Rock Hill
23	LITSUGAR.ORC	CW-593	Little Sugar Cr at US Hwy 521 in NC
24	LITTLEWAT.ORC	CW-040	Little Wateree Cr at S-21-41, 5 mi. E of Winnsboro
25	MCALP2.ORC	CW-226	Mc Alpine Cr at US 521 in NC
26	MCALP5.ORC	CW-064	Mc Alpine Cr at S-29-64
27	MCMULLEN.ORC	CW-684	McMullen Cr at NC Hwy 51
28	NEELYS.ORC	CW-227	Neelys Cr At S-46-997
29	ROCKY1.ORC	CW-236	Lower Rocky Cr
30	ROCKY2.ORC	CW-175	Rocky Cr On S-12-141 SE of Great Falls
31	ROCKYUP.ORC	CW-002	Rocky Cr At S-12-335, 3.5 mi E of Chester
32	RUM.ORC	CW-232	Rum Cr At S-29-187
33	STEELE.ORC	CW-011	Steel Cr At S-91-270
34	STEELE3.ORC	CW-009	Steel Cr At S-91-22 N of Fort Mill
35	SUGAR1.ORC	CW-592	Sugar Cr At NC Hwy 51 at Pineville, NC
36	SUGAR2.ORC	CW-036	Sugar Cr On Sec. Rd 36
37	SUGAR3.ORC	CW-627	Sugar Cr u/s of confluence with McAlpine Cr
38	SUGAR4.ORC	CW-013	Sugar Cr near Fort Mill
39	TINKERS.ORC	CW-234	Tinkers Cr at S-12-599
40	TWELVE2.ORC	CW-083	Twelve Mile Cr at S-29-55, 0.3 mi NW of Van Wick

41	UNAMD.ORC	CW-221	Un-named trib to Catawba R. at SC-161, 0.4 mi off 7
42	WATEREE2.OLC	CW-207	Lk Wateree at end of S-20-291
43	WATEREE3.OLC	CW-209	Lower Lk Wateree
44	WATEREE5.OLC	CW-208	Lk Wateree at S-20-101, E-NE of Winnsboro
45	WILDCAT.ORC	CW-096	Wildcat Cr at S-91-998, 9 mi. E-NE of McConnels
46	WILDCAT2.ORC	CW-006	Wildcat Cr at S-91-650
47	WYLIE16.OLC	CW-027	Lk Wylie, segment 16
48	WYLIE17.OLC	CW-665	Lk Wylie, segment 17
49	WYLIE5.OLC	CW-197	Lk Wylie, segment 5
50	WYLIE9.OLC	CW-230	Lk Wylie, segment 16

3. MODEL REFINEMENTS

GENERAL

WARMF periodically undergoes modifications to its computer code in response to the objectives of a particular model application. WARMF was recently updated to provide greater flexibility in assigning parameters related to adsorption and algae (phytoplankton) growth in reservoirs. Though these modifications do not change the actual representation of these processes in the model code, they are required to facilitate the calibration of nutrients and algae by allowing more flexibility in setting model coefficients.

Other changes in computer code of WARMF were made as part of general model maintenance. Changes to the representation of biological oxygen demand (BOD) in WARMF fall under this category. Previously, WARMF BOD was modeled in terms of dissolved organic carbon (DOC). DOC includes organic carbon or organic acids that are produced by the decay of organic matters in land catchments. Previously, BOD loading was converted to DOC using basic stoichiometry, and then the decomposition of DOC and the resulting consumption of oxygen were tracked in the model. Because of a concurrently developing application of WARMF for mercury TMDLs, this algorithm has been upgraded to simulate BOD and DOC separately. BOD now represents the oxygen consuming organic matter discharged by wastewater treatment plants. DOC now represents the organic acids, which are a principal carrier of mercury through the watershed system.

ADSORPTION ISOTHERM

In WARMF phosphorous dissolved in the water column may adsorb to sediment. The adsorption isotherm parameter in the model controls the sediment adsorption capacity of constituents. This parameter is commonly used during model calibration to partition the dissolved and adsorbed fractions of a constituent. The isotherm can apply to soil pore water and also to the water column of rivers and lakes.

The river and lake water column isotherm was recently modified to allow more flexibility during calibration. Previously, the isotherm for suspended particles in the water column was not allowed to vary between regions in a given watershed. Now this parameter can vary by river segment and reservoir so that adsorption processes in large multi-reservoir watersheds can be more accurately modeled.

This parameter should be adjusted with caution. As with many model parameters, it should be verified that significant variations of this parameter especially between adjacent river segments do not unrealistically affect the simulation. It is suggested that this parameter vary significantly only between subwatersheds divided by a reservoir. As an example, it was verified that varying the isotherm from subwatershed to subwatershed with a reservoir in between from approximately 5,000 L/kg to 20,000 L/kg did not cause unrealistic dissolved or adsorbed values for the Catawba River Watershed. A precautionary note is shown in the river and reservoir adsorption input dialog boxes in WARMF, shown in Figure 3-1 and Figure 3-2.

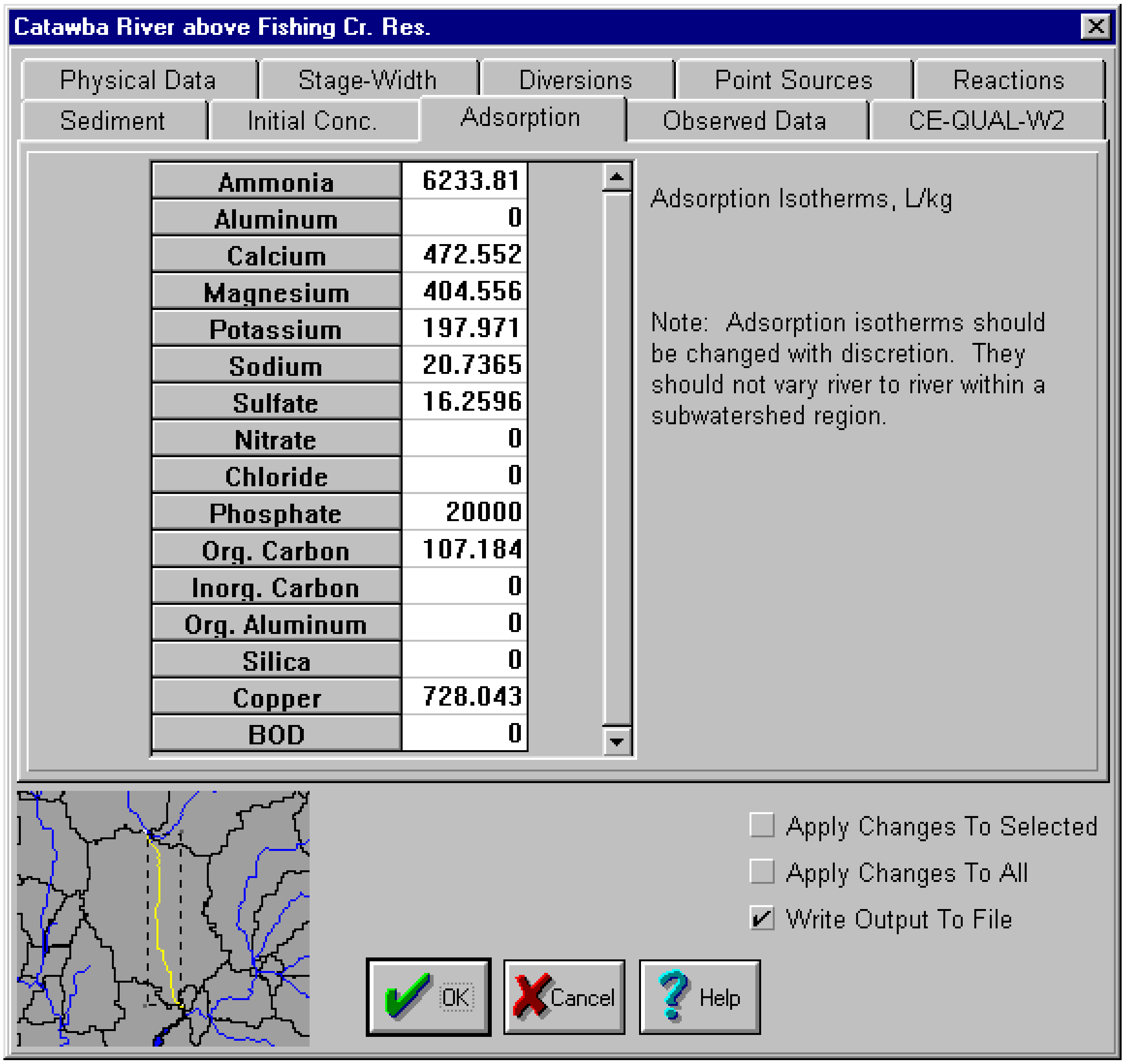


Figure 3-1
WARMF River Input Dialog Showing River-Dependent Adsorption Coefficients.

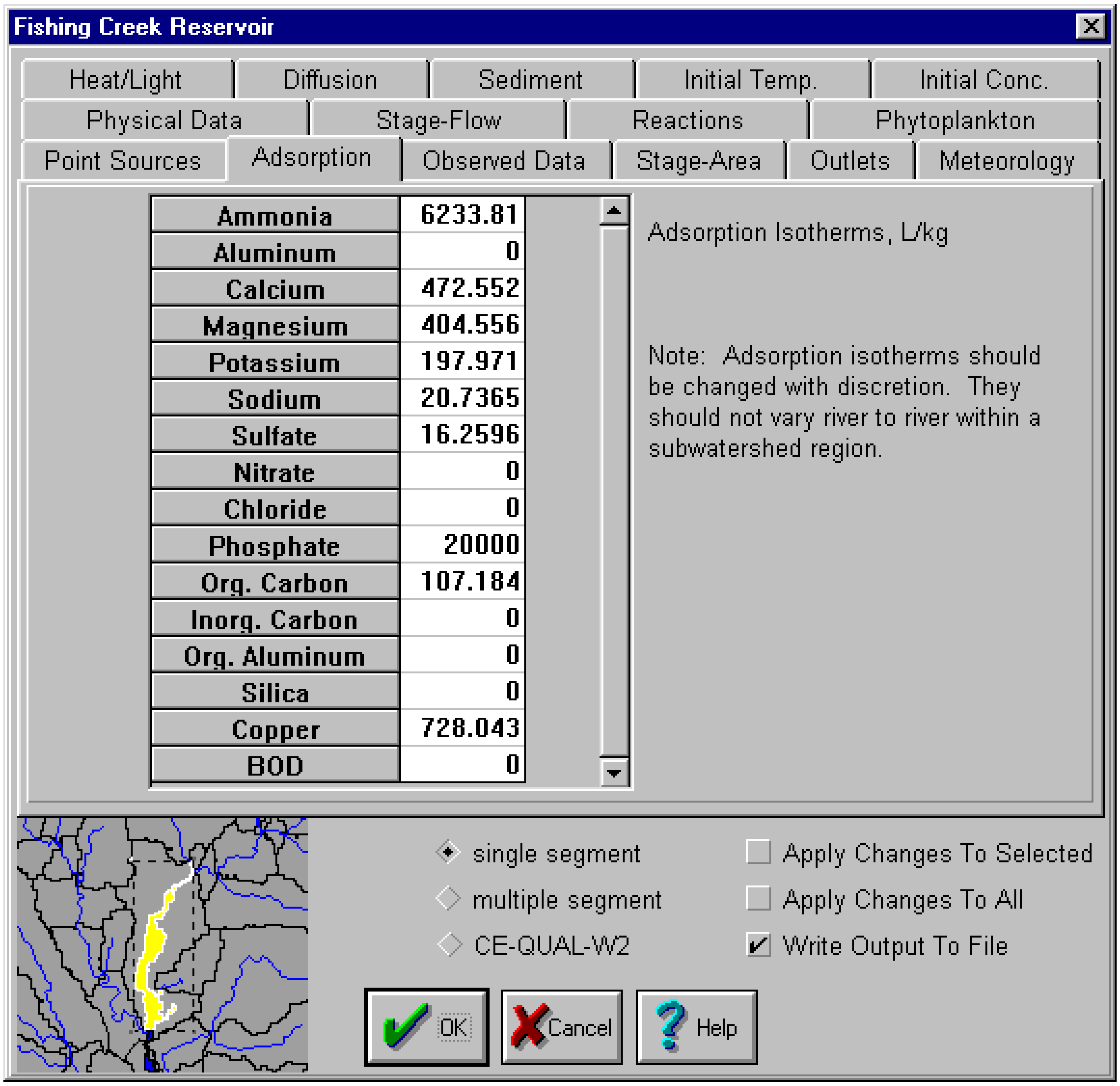
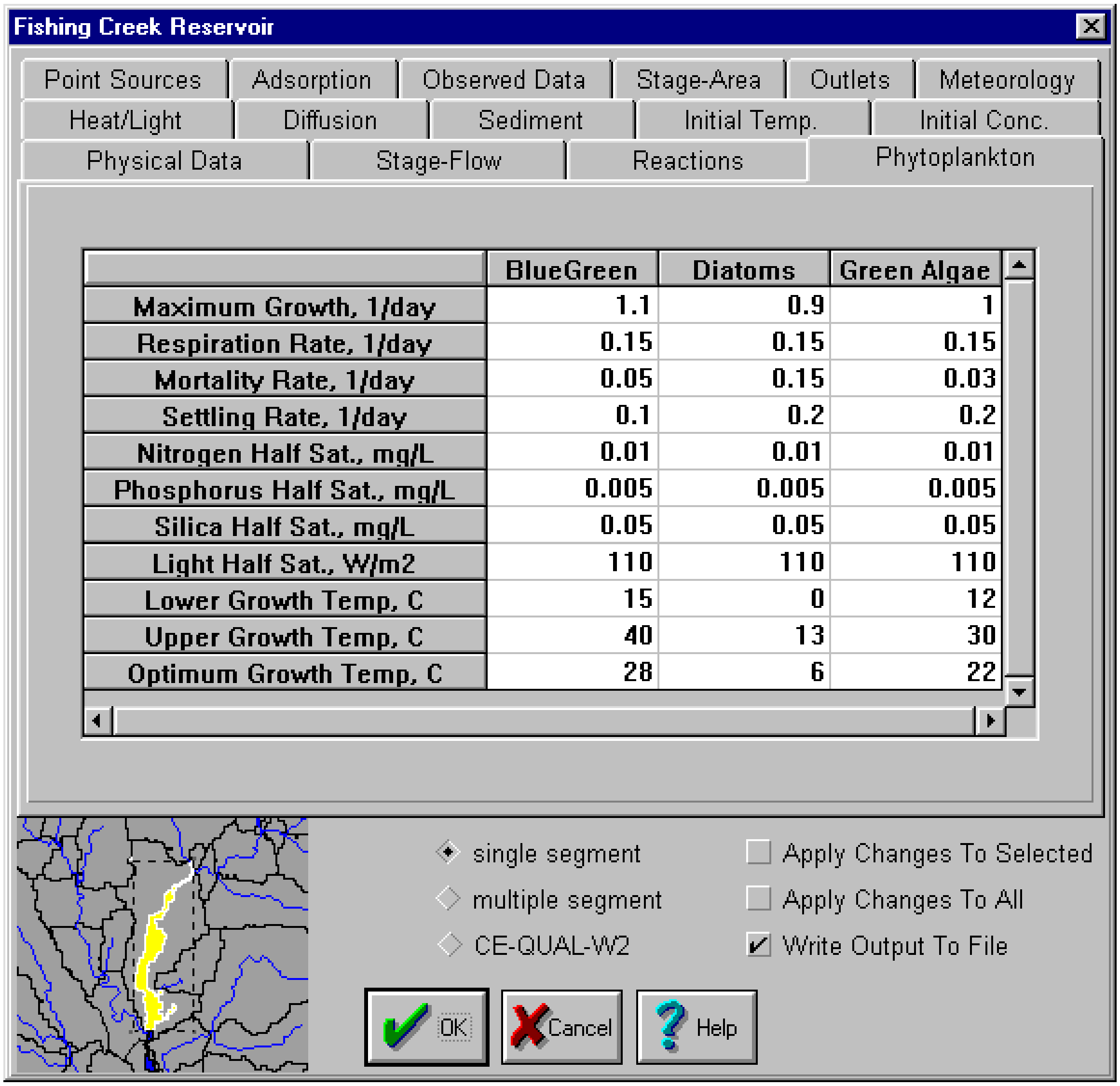


Figure 3-2
WARMF Lake Input Dialog Showing Reservoir-Dependent Adsorption Coefficients.

The model enhancement to allow spatially varying adsorption isotherms did not significantly change model calibration results. These changes did, however, give the USC researchers flexibility to make adjustments to improve the final calibration for phosphorus. Calibration results for total phosphorus are presented in Chapter 5 of this report.

ALGAE PARAMETERS

The ability to adjust parameters affecting algae growth was also improved. Previous versions of the model required algae parameters (growth rates, temperature coefficients, nutrient half saturation rates) to be constant for all reservoirs within a watershed. Now, the parameters can vary by reservoir. This is a particular benefit to large systems such as the Catawba River watershed where algae communities and the conditions affecting them likely vary between reservoirs. The lake input dialog listing algae input variables is shown for Fishing Creek Reservoir in Figure 3-3.



	BlueGreen	Diatoms	Green Algae
Maximum Growth, 1/day	1.1	0.9	1
Respiration Rate, 1/day	0.15	0.15	0.15
Mortality Rate, 1/day	0.05	0.15	0.03
Settling Rate, 1/day	0.1	0.2	0.2
Nitrogen Half Sat., mg/L	0.01	0.01	0.01
Phosphorus Half Sat., mg/L	0.005	0.005	0.005
Silica Half Sat., mg/L	0.05	0.05	0.05
Light Half Sat., W/m2	110	110	110
Lower Growth Temp, C	15	0	12
Upper Growth Temp, C	40	13	30
Optimum Growth Temp, C	28	6	22

Figure 3-3
WARMF Lake Input Dialog Showing Reservoir-Dependent Phytoplankton Coefficients.

The model enhancement to allow spatially varying phytoplankton coefficients does not necessarily change calibration results. Again, these changes allow the USC researchers greater flexibility to adjust calibration for chlorophyll-a and nutrients. Calibration results for chlorophyll-a and nutrients are presented in Chapter 5 of this report.

BOD MODEL RESULTS

To better represent the oxygen consumption due to BOD loading, an explicit BOD state variable was added to WARMF. The main source of BOD loading in the Catawba River watershed is municipal point sources. A small fraction of nonpoint BOD loading is assumed to come from animal waste on the land surface. WARMF decays BOD using a first order reaction.

The resulting BOD concentration in streams and lake were compared to observed data. Figure 3-4 shows the simulated and observed BOD for the Catawba River above Sugar Creek. In general, the simulated follows the fluctuation of the observed. The model also slightly under-predicts some of the higher levels of BOD; thus the simulated average is slightly lower that that of the observed data. The average observed and simulated concentrations are 0.8 mg/l and 1.0 mg/l, respectively.

Figure 3-5 compares the simulated and observed BOD in the Catawba River downstream of Sugar Creek confluence. The observed BOD data vary from 0.5 mg/l to nearly 3 mg/l, while the simulated varies from less than 0.6 mg/l to 2 mg/l. The model under predicts the maximum observed BOD by about 1 mg/l. However, the simulated and the observed have similar averages.

Figure 3-6 shows the comparison of simulated and observed BOD at station SC 223 on Fishing Creek (approximately half way between the headwaters and mouth of the creek). Both simulated and observed BOD values average bout 2 mg/l. Their values can vary between 1 and 5 mg/l.

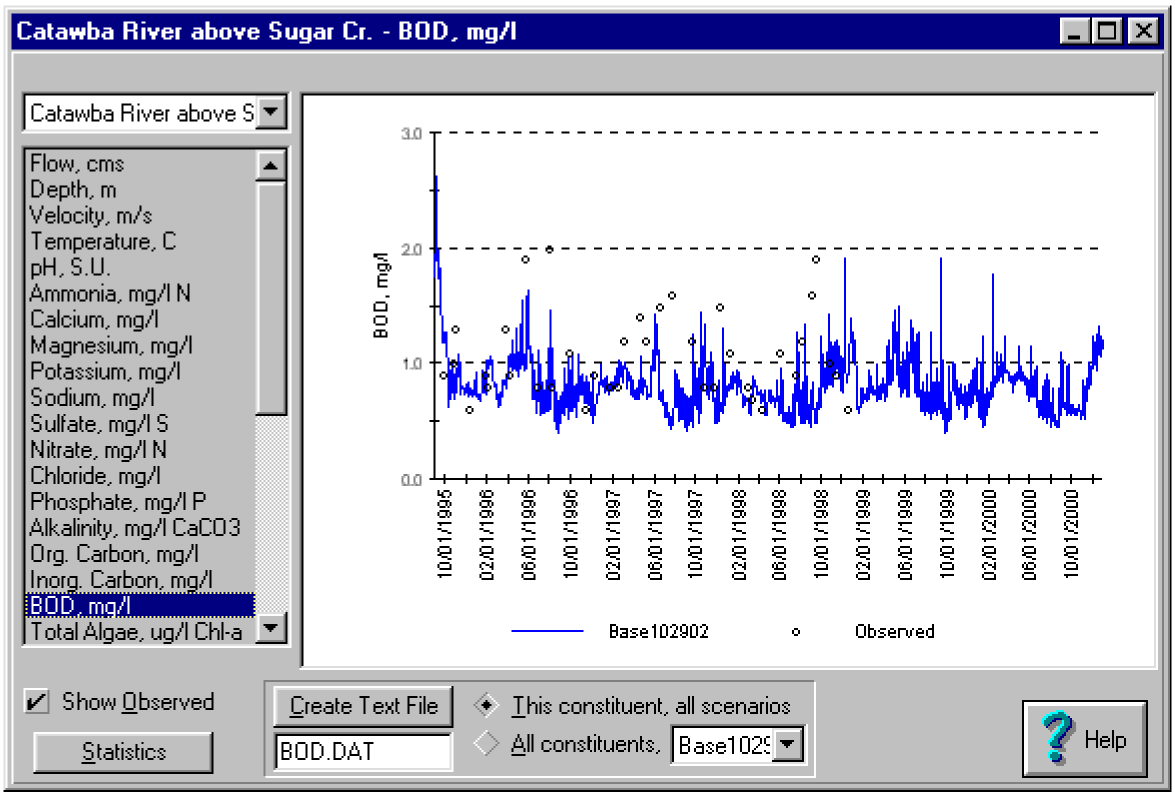


Figure 3-4
Simulated and Observed BOD in the Catawba River upstream of Sugar Creek.

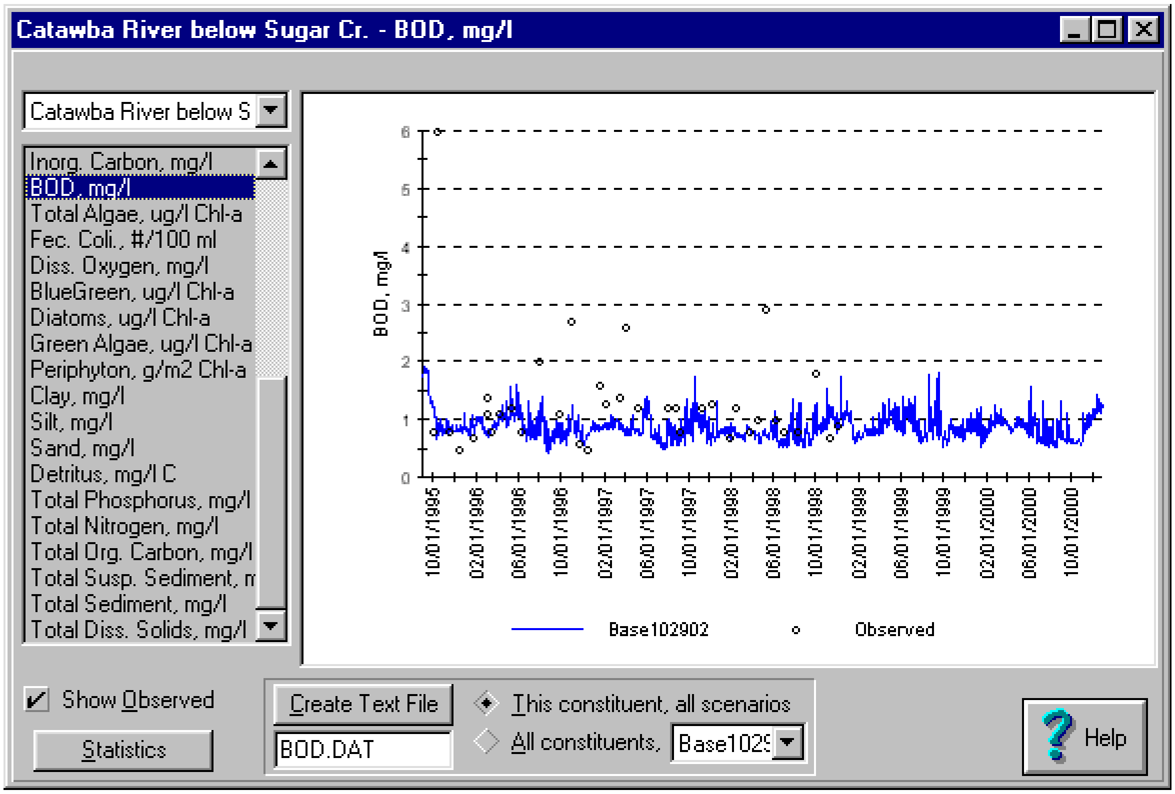


Figure 3-5
Simulated and Observed BOD in the Catawba River downstream of Sugar Creek.

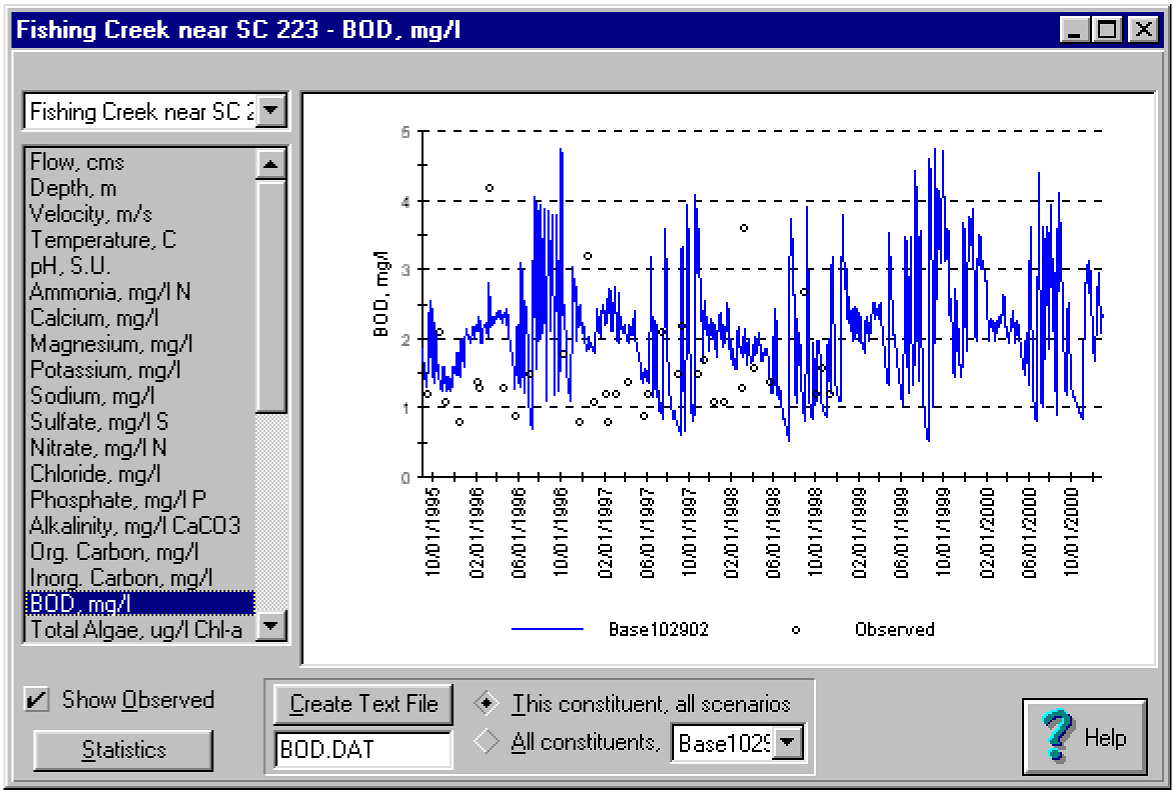


Figure 3-6
Simulated and Observed BOD in Fishing Creek at station SC 223.

Figure 3-7 compares the simulated and observed BOD for the surface water of Fishing Creek Reservoir. The simulated BOD fluctuated between 1 to 2 mg/l, whereas the observed BOD is shown to fluctuate between 1 mg/l and 7 mg/l.

Figure 3-8 compares the simulated and observed BOD for the surface water of Lake Wateree. The simulated BOD fluctuated between 0.5 to 1.5 mg/l. The observed BOD fluctuated between 0.5 and 3.6 mg/l.

Clearly, the model has under predicted BOD for the surface water of both reservoirs.

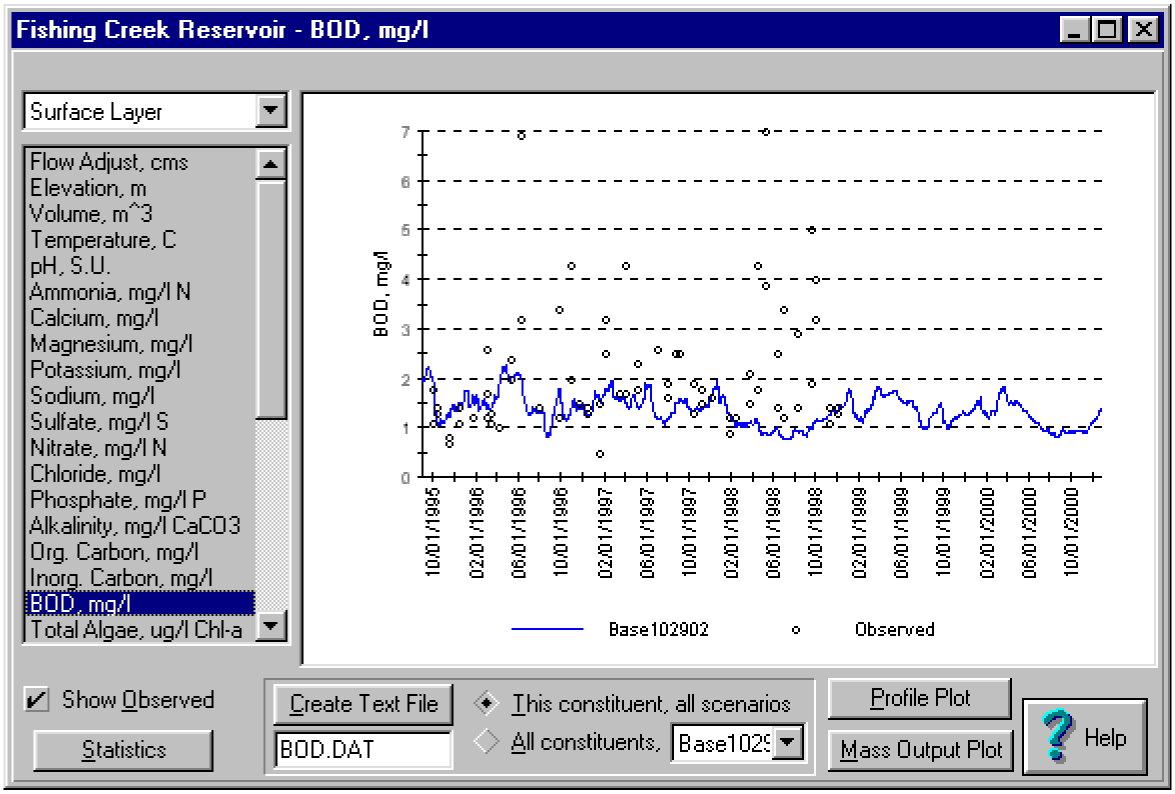


Figure 3-7
Simulated and Observed BOD in Fishing Creek Reservoir.

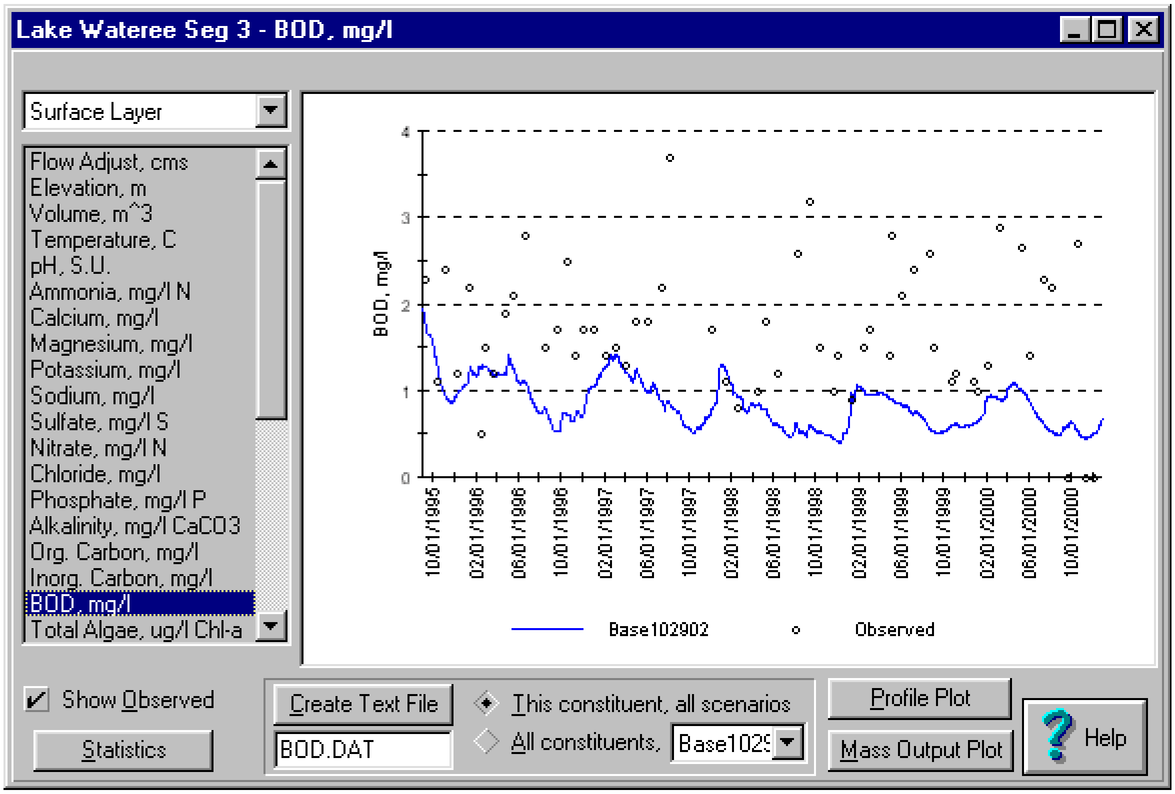


Figure 3-8
Simulated and Observed BOD in Lake Wateree.

Observations

WARMF appears to have slightly under predicted the measured BOD for the river stations. The reason is that the model has probably not accounted for all BOD input to the river system. BOD input from point source discharge is monitored and reported on a regular basis. The error of BOD input from point source load is probably small. The nonpoint source load of BOD, however, is not monitored. It is possible that the input data, as currently specified, has caused the model to under predict the BOD load from land catchments.

WARMF appears to have grossly under predicted the measured BOD for the reservoir water. The reason is that the model is predicting the concentration of BOD discharged by point source and nonpoint source loads. The model has attenuated the BOD to very low values in a rational manner. The observed BOD, on the other hand, probably included oxygen consuming organic matter not derived from the point and nonpoint source loads. This is evident from the observation that the measured BOD concentrations were 7 mg/l in Fishing Creek Reservoir and 3.6 mg/l in Lake Wateree, both higher than the observed BOD concentrations in their tributary rivers.

It is common knowledge that dissolved oxygen in the reservoir is mostly controlled by photosynthesis and respiration of algae rather than by the BOD of point and nonpoint source loads. Because WARMF accounts for photosynthesis and respiration in the budget of dissolved oxygen, the model is expected to simulate the dissolved oxygen profiles of the reservoir accurately, despite the apparent under prediction of BOD.

4. FLOW, TEMPERATURE AND DISSOLVED OXYGEN

GENERAL PROCEDURE

In model calibration, the parameters of the model are adjusted to match the simulated water quality concentrations to the observed. The results for hydrology, temperature, and dissolved oxygen will be described first, followed by the discussion of nutrient and algae simulations from Lake Wylie to Lake Wateree.

The model parameters adjusted include initial soil conditions, land application rates of fertilizer, adsorption coefficients of soil, and decay rates. The major emphasis is placed on the Fishing Creek region, where USC monitoring data were removed, the region downstream of Bower point source discharge, whose waste load characteristics were changed, and also the region, where the observed TP data were revised.

FLOW SIMULATION

Flow data are available for the following locations:

- Fishing Creek at Rd 347
- Fishing Creek at station S-46-503
- Catawba River above Sugar Creek
- McAlpine Creek at Sardis Rd
- Little Sugar Creek at Archdale Drive

The comparisons of simulated and observed stream flows for those locations are shown respectively in Figure 4-1, Figure 4-2, Figure 4-3, Figure 4-4, and Figure 4-5.

From these comparisons, WARMF appears to predict the flow very well.

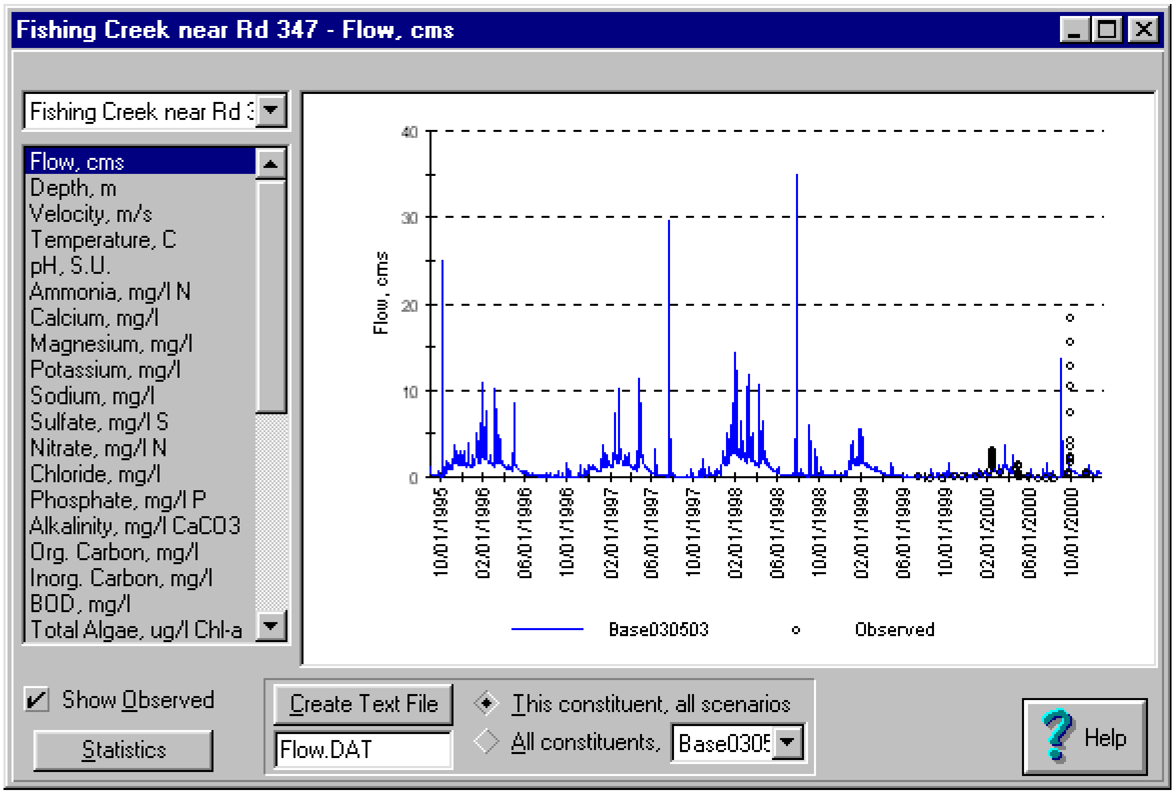


Figure 4-1
Simulated and observed flows in Fishing Creek near Rd 347.

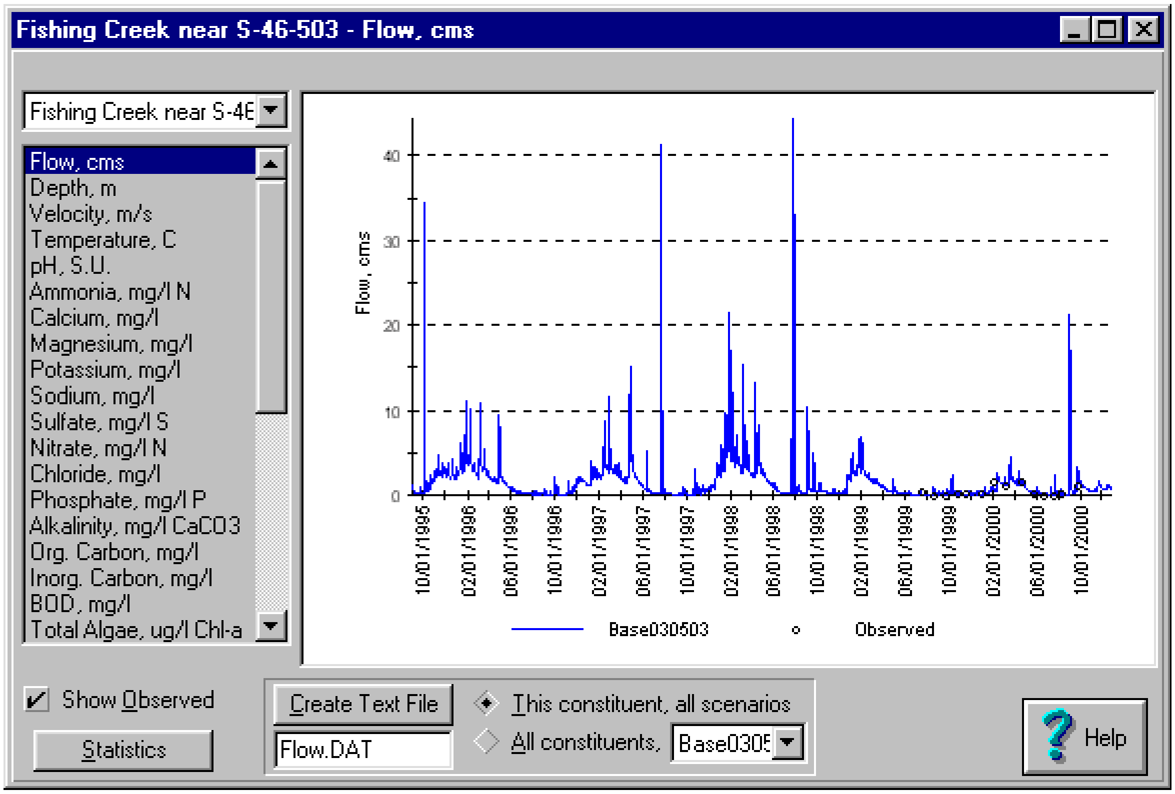


Figure 4-2
Simulated and observed flows in Fishing Creek near S-46-503.

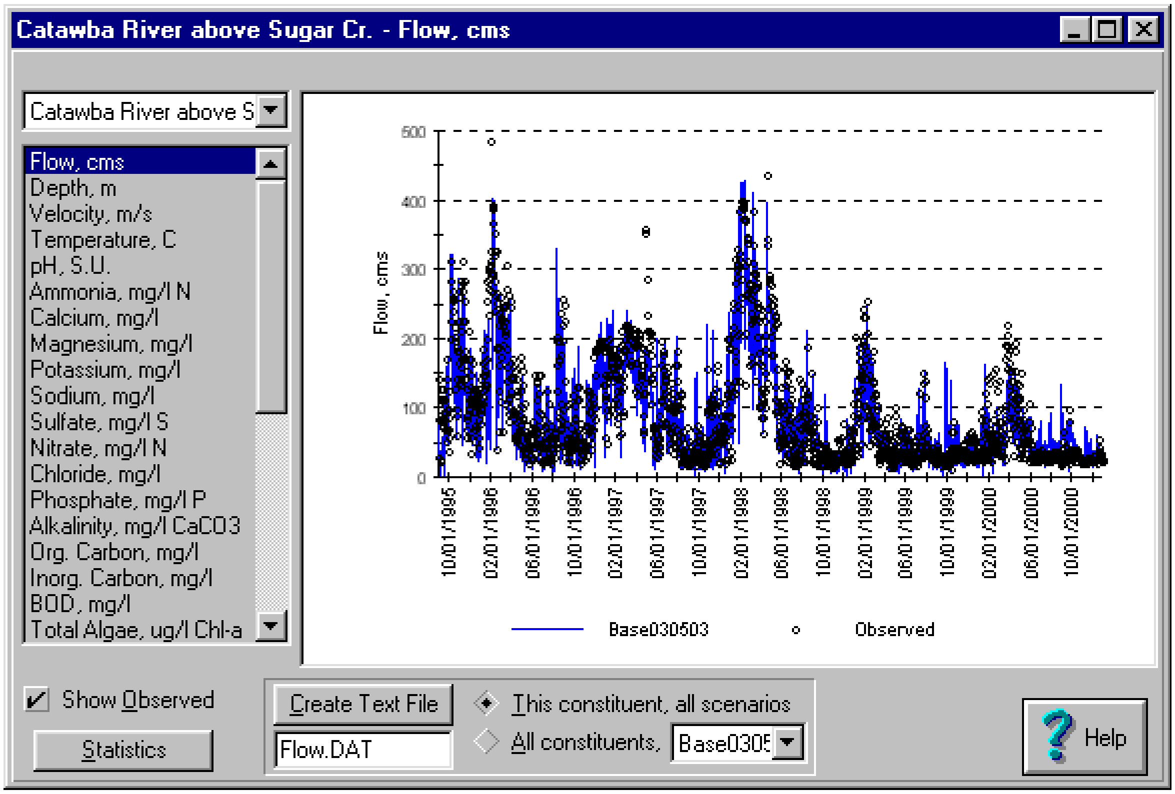


Figure 4-3
Simulated and observed flows in the Catawba River above Sugar Creek.

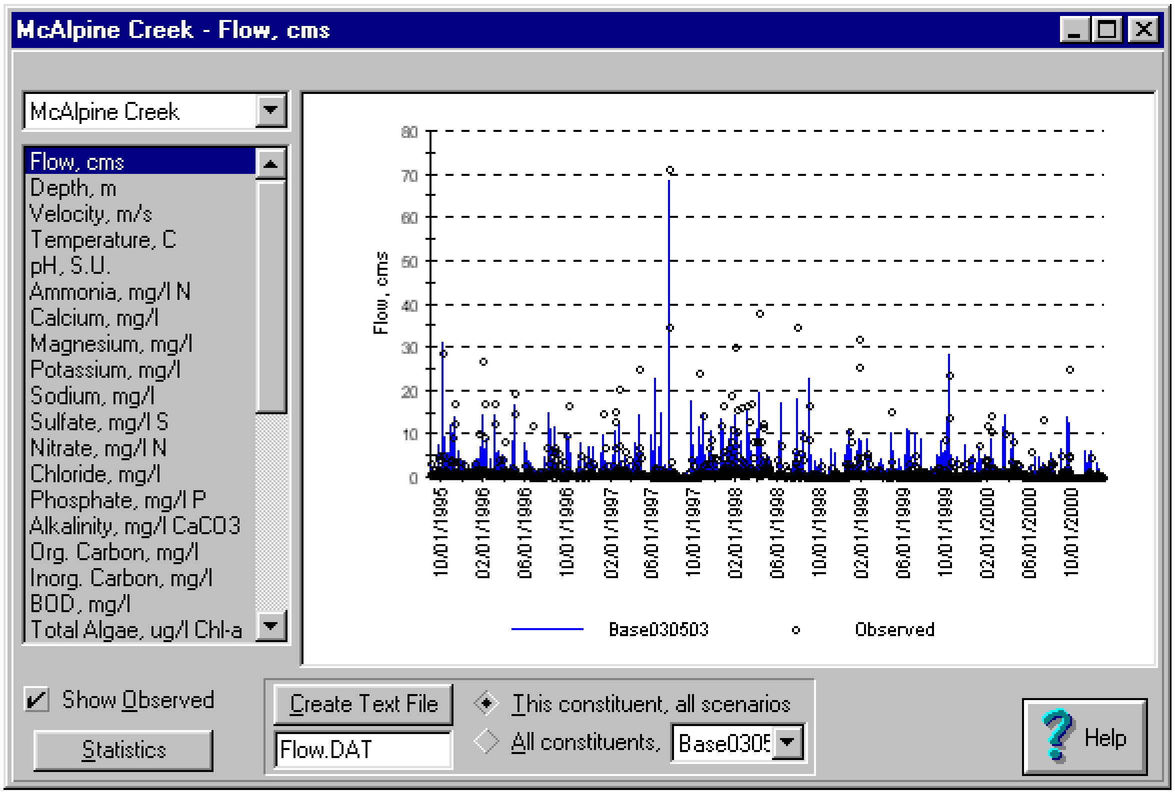


Figure 4-4
Simulated and observed flow in McAlpine Creek at Sardis Road.

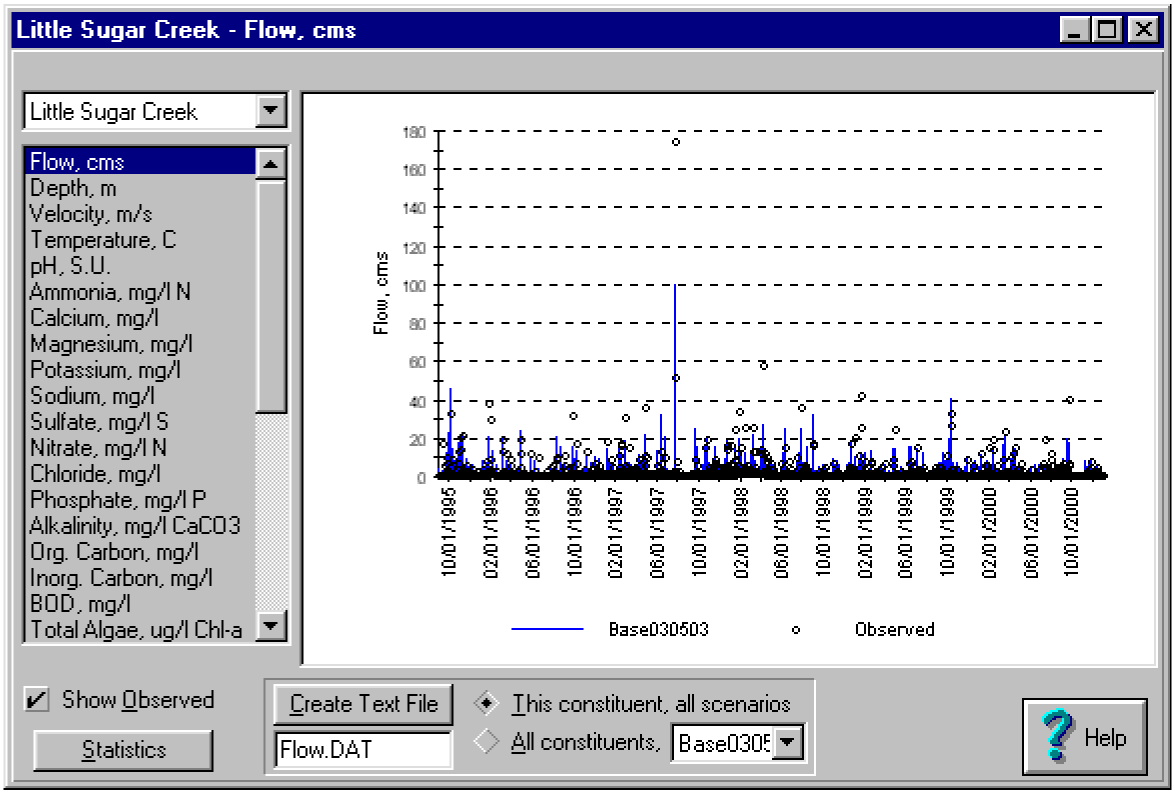


Figure 4-5
Simulated and observed flow in Little Sugar Creek at Archdale Drive.

TEMPERATURE SIMULATION

Observed water temperature data are shown at the following locations:

- Fishing Creek at SC 223
- Fishing Creek at S-46-503
- Catawba River above Sugar Creek Confluence
- Fishing Creek Reservoir
- Cedar Creek Reservoir
- Lake Wateree

The comparisons of simulated and observed water temperature for those locations are shown respectively in Figure 4-6, Figure 4-7, Figure 4-8, Figure 4-9, Figure 4-10, and Figure 4-11.

From these comparisons, WARMF appears to have simulated the seasonal variations of water temperatures for rivers and lakes very well.

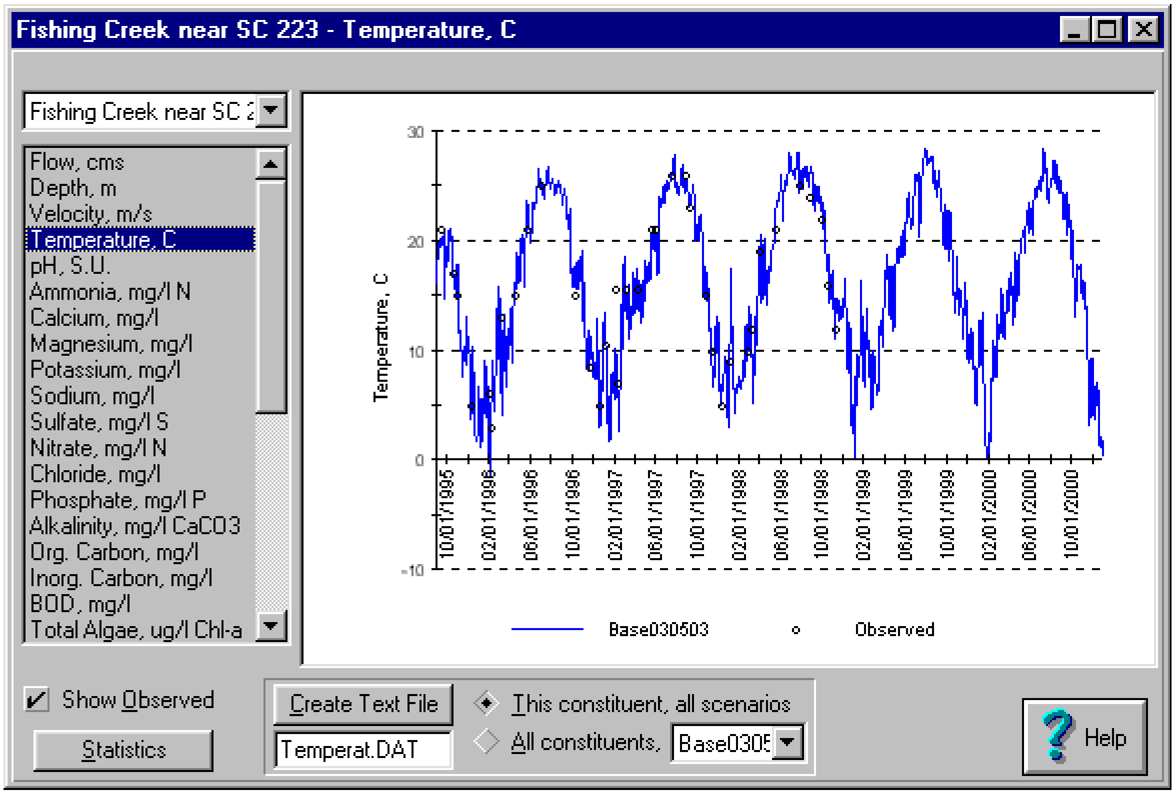


Figure 4-6
Simulated and observed water temperatures in Fishing Creek near SC 223.

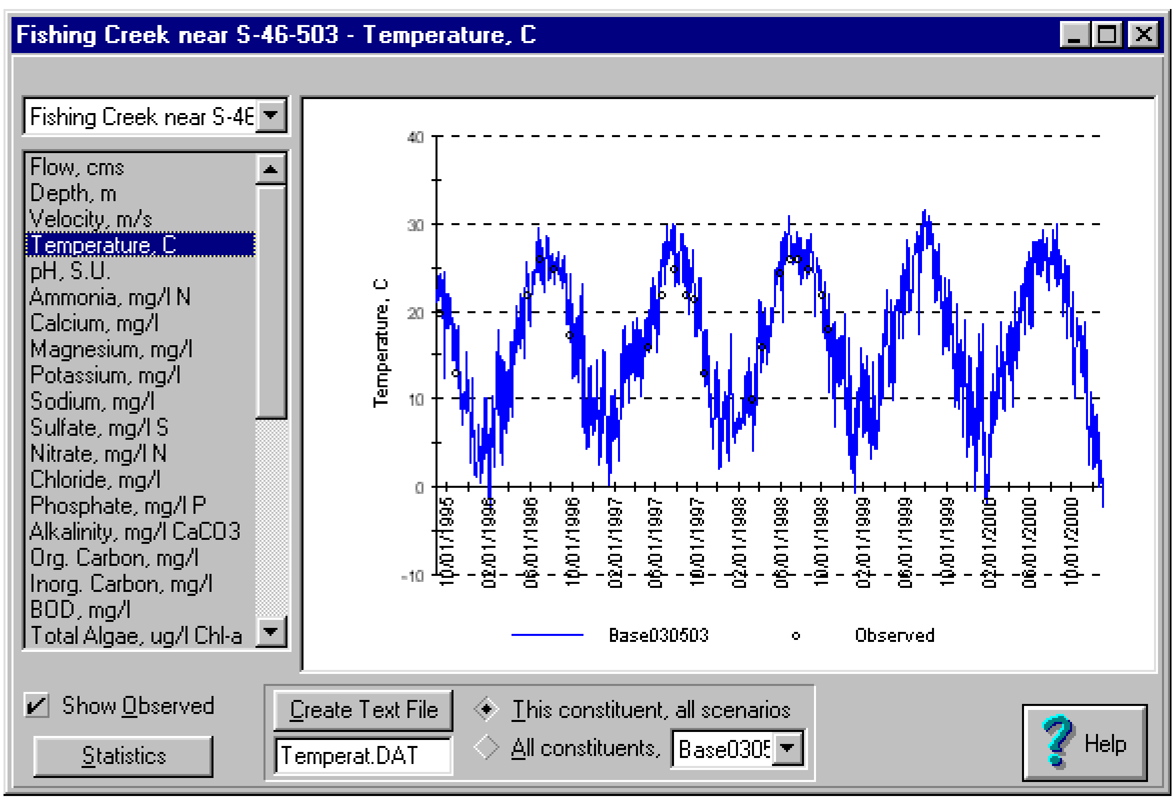


Figure 4-7
Simulated and observed water temperatures in Fishing Creek near S-46-503.

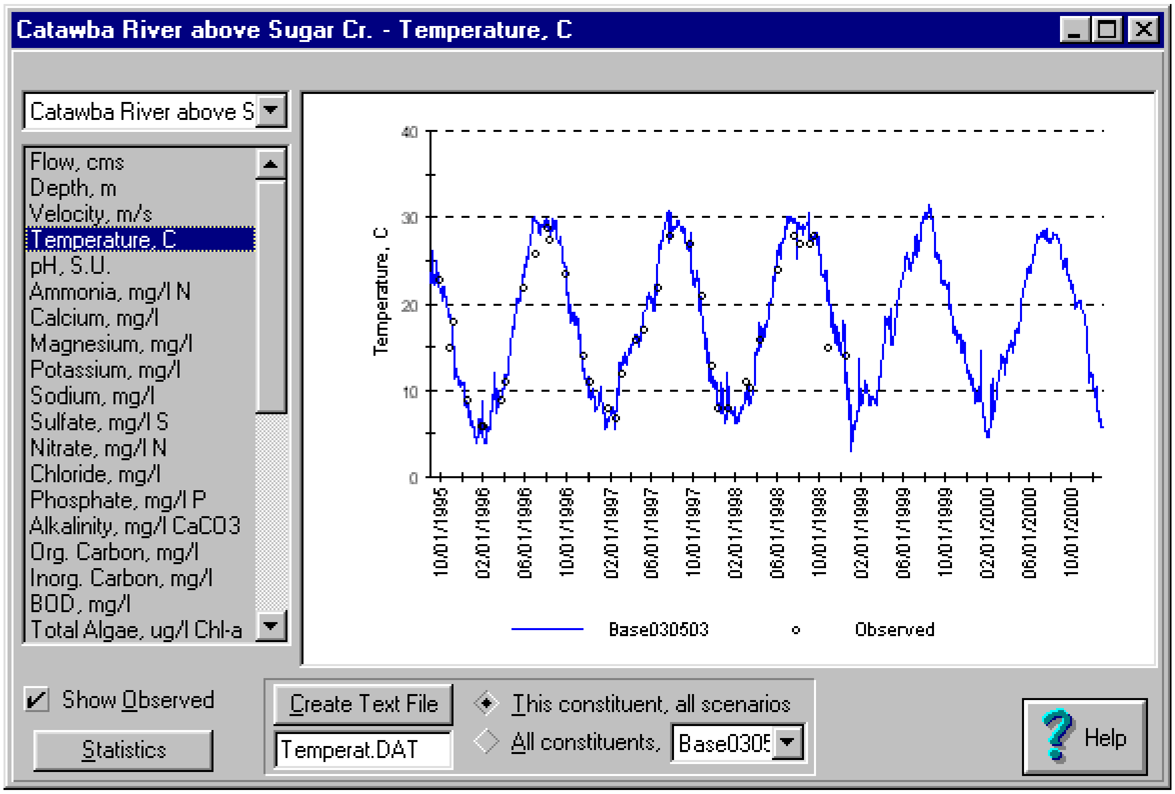


Figure 4-8
Simulated and observed water temperatures in the Catawba River above Sugar Creek.

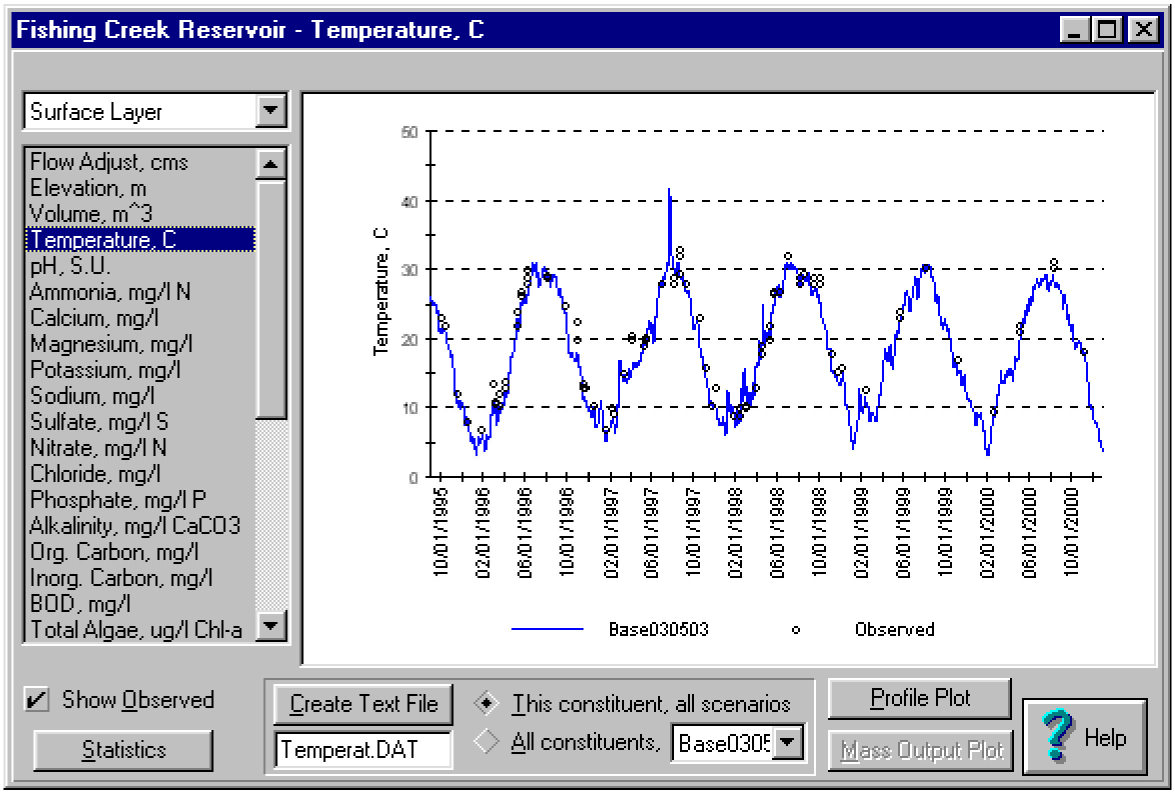


Figure 4-9
Simulated and observed surface water temperatures in Fishing Creek Reservoir.

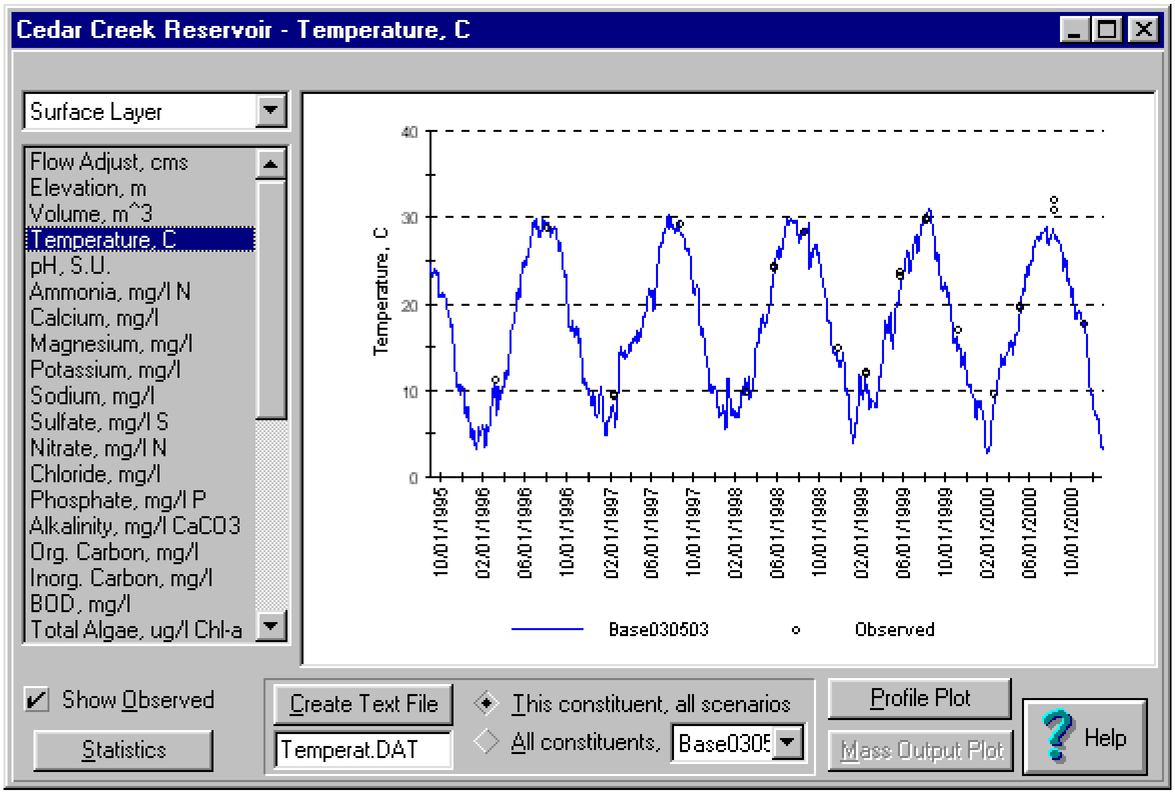


Figure 4-10
Simulated and observed surface water temperatures in Cedar Creek Reservoir.

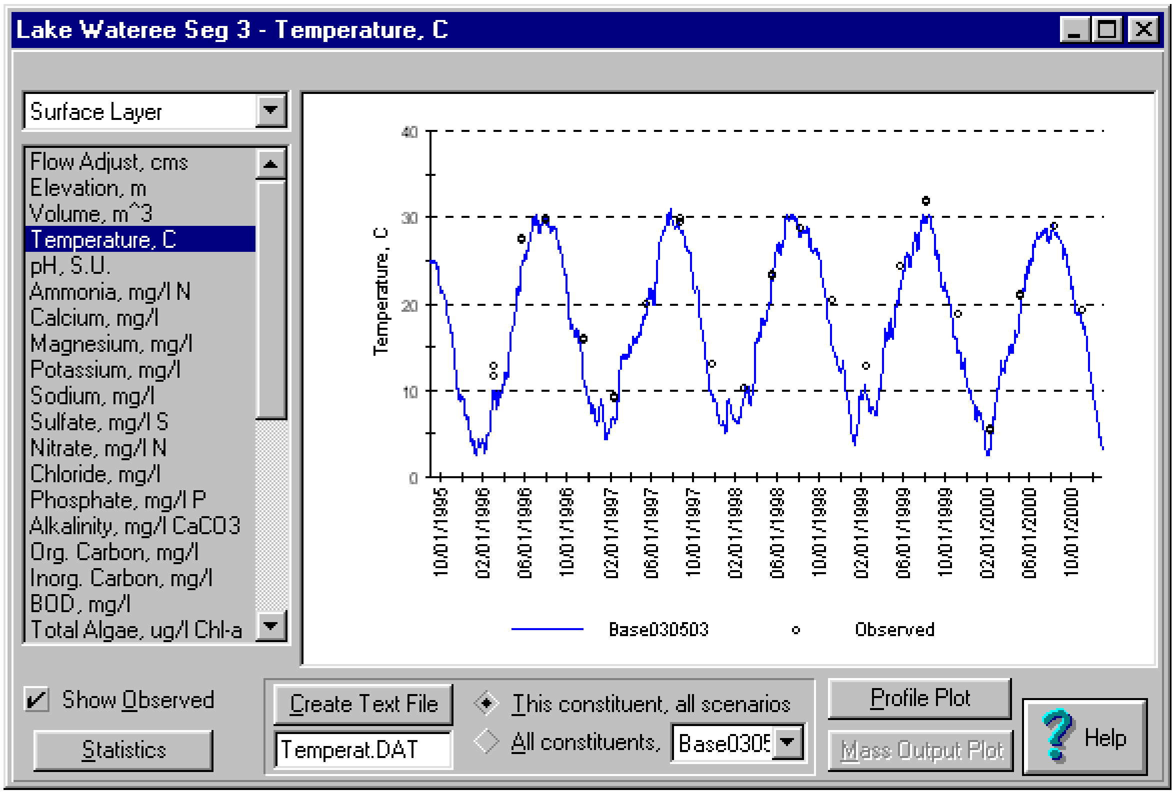


Figure 4-11
Simulated and observed surface water temperatures in Lake Wateree.

DISSOLVED OXYGEN SIMULATION

Dissolved oxygen data for rivers, particularly tributaries to Fishing Creek Reservoir, are relatively sparse. Consequently, the comparisons are made only for reservoirs. Figure 4-12 compares the simulated and observed DO in the surface water of Fishing Creek Reservoir. Figure 4-13 compares the simulated and observed DO in the surface water of Cedar Creek Reservoir. Figure 4-14 compares the simulated and observed DO in the surface water of Lake Wateree.

Based on these comparisons, WARMF appears to have simulated the seasonal fluctuations of DO reasonably well. The ranges of simulated fluctuations are close to the observed. The observed DO show values as high as 14 to 16 mg/l on occasions in Fishing Creek Reservoir. These high values were probably caused by large algal blooms, which were simulated by the model but not as high as observed. The ability of WARMF to simulate accurately for the DO of reservoir, despite the under prediction of BOD as discussed in the previous chapter, support the common knowledge that DO in reservoirs is not controlled by BOD of waste discharges.

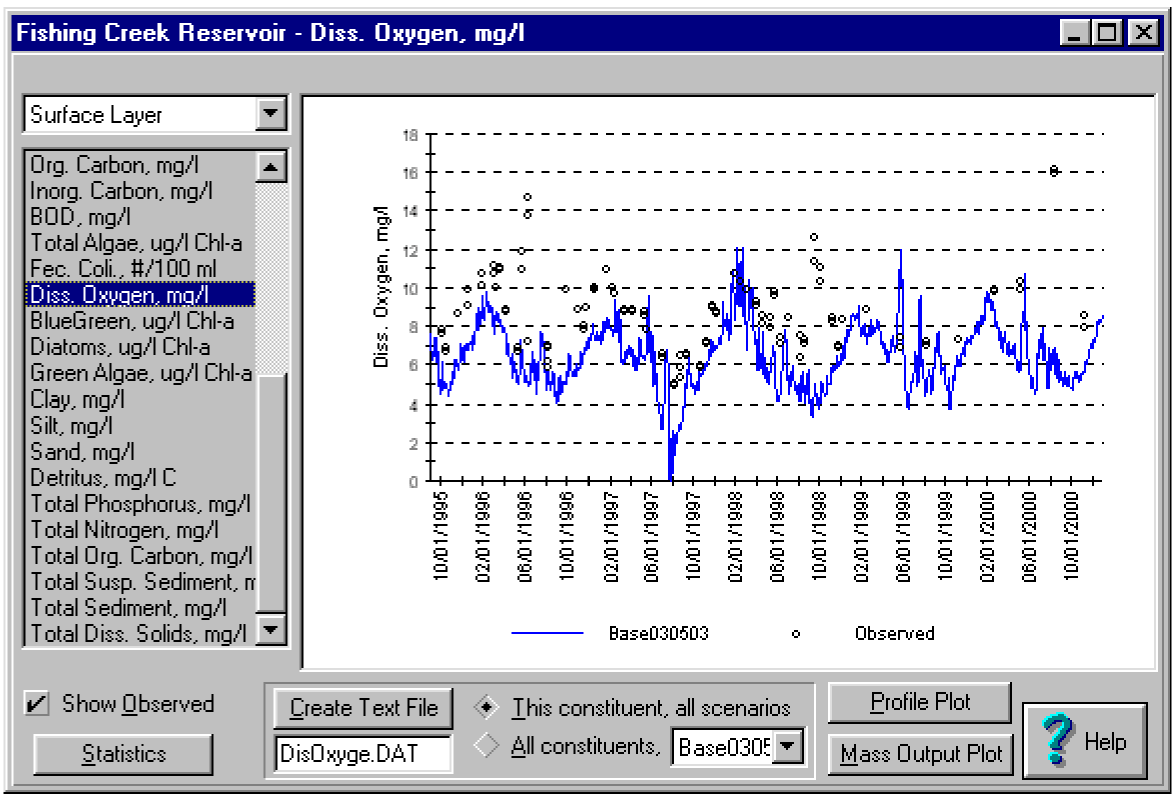


Figure 4-12
Simulated and observed DO in Fishing Creek Reservoir.

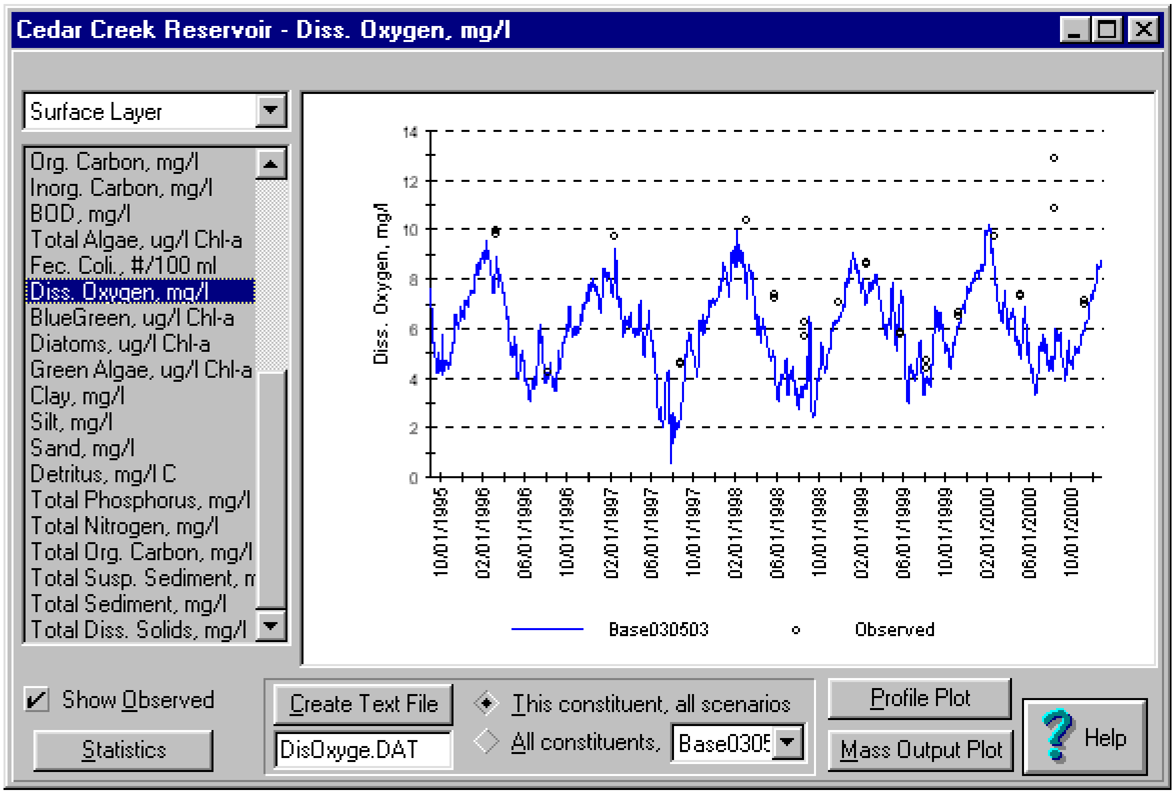


Figure 4-13
Simulated and observed DO in Cedar Creek Reservoir.

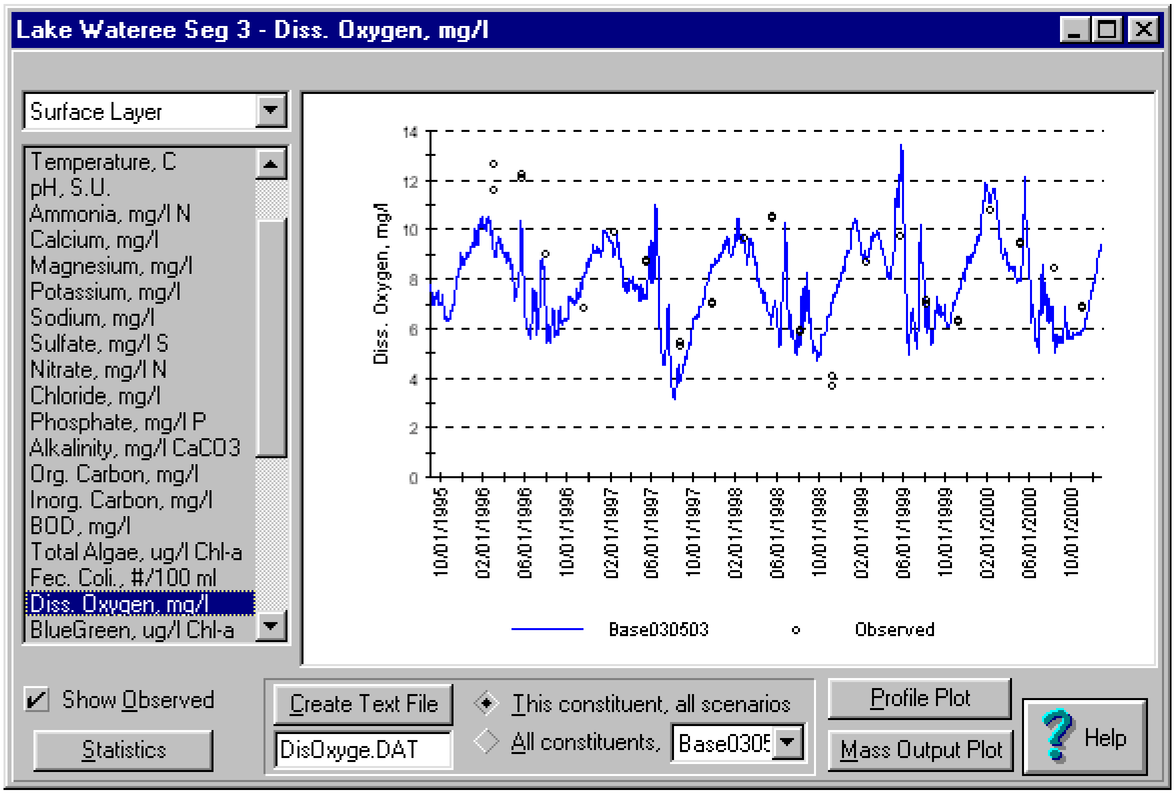


Figure 4-14
Simulated and observed DO levels in Lake Wateree.

5. NUTRIENTS AND ALGAE

In this section, simulation results for nutrients and algae will be discussed. Nutrients include ammonia (NH3), nitrogen (NO3), total nitrogen (TN), phosphate (PO4), and total phosphorus (TP). Total chlorophyll concentration is used to represent the sum of three algae groups, diatoms and green and blue-green algae.

The simulation results will be discussed from upstream to downstream locations along the Catawba River. The first location is Lake Wylie, the most upstream water body of the Lower Catawba River.

LAKE WYLIE

Lake Wylie is divided into multiple stratified segments in WARMF. The results for the most downstream segment of the reservoir (near the dam) will be discussed here. This segment is referred to as segment 9, according to the numbering system used in WARMF.

Results for ammonia are shown in Figure 5-1. Figure 5-2shows the results for nitrate, and Figure 5-3 shows the results for total nitrogen. Phosphate and TP comparisons are shown in Figure 5-4 and Figure 5-5. Algae comparisons are made in Figure 5-6.

The comparisons indicate that WARMF has simulated all water quality parameters reasonably well; the simulated values fluctuate seasonally within the ranges of observed data. Notable differences are that the model appears to over predict phosphorous concentration and slightly over predicts total phosphate concentration. Also, the observed range of total nitrogen is slightly larger than the simulated values.

The simulated algae concentration is very close to the observed chlorophyll level. The match is particularly good for 1996 when more observed data are available. The model has simulated the algal blooms occurring in the summer months, but the peak values are slightly lower than the observed. This is understandable, because the model calculates the daily averages whereas the observed values are based on the samples taken instantaneously likely during a daylight hour.

The model calculates the growth rate of algae as a function of light, temperature, and nutrients (ammonia, nitrate, and phosphorus). The dynamic calculations involving multiple factors have resulted in the reasonable prediction of total algae concentrations. These results are achieved by using same coefficients for all rivers and reservoirs in the Catawba River Basin. Further improvements may be made by varying algae coefficients specifically for each reservoir.

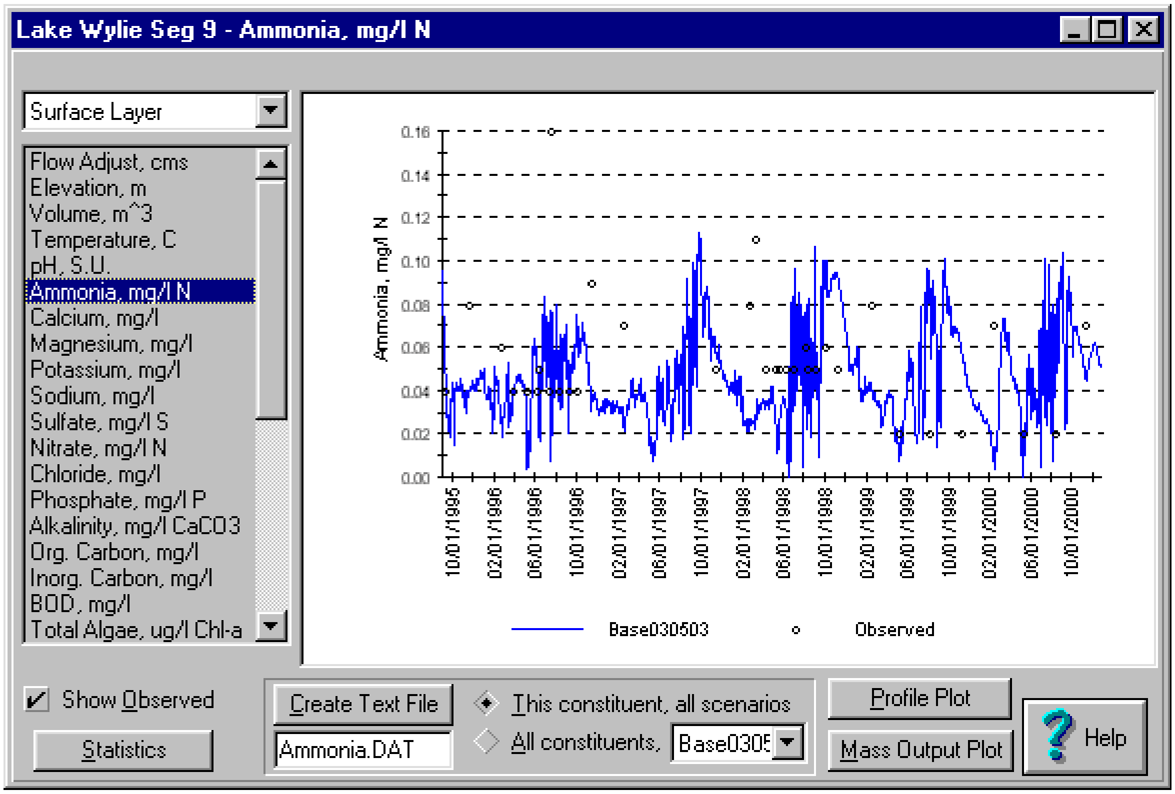


Figure 5-1
Simulated and observed NH3 at Segment 9 of Lake Wylie.

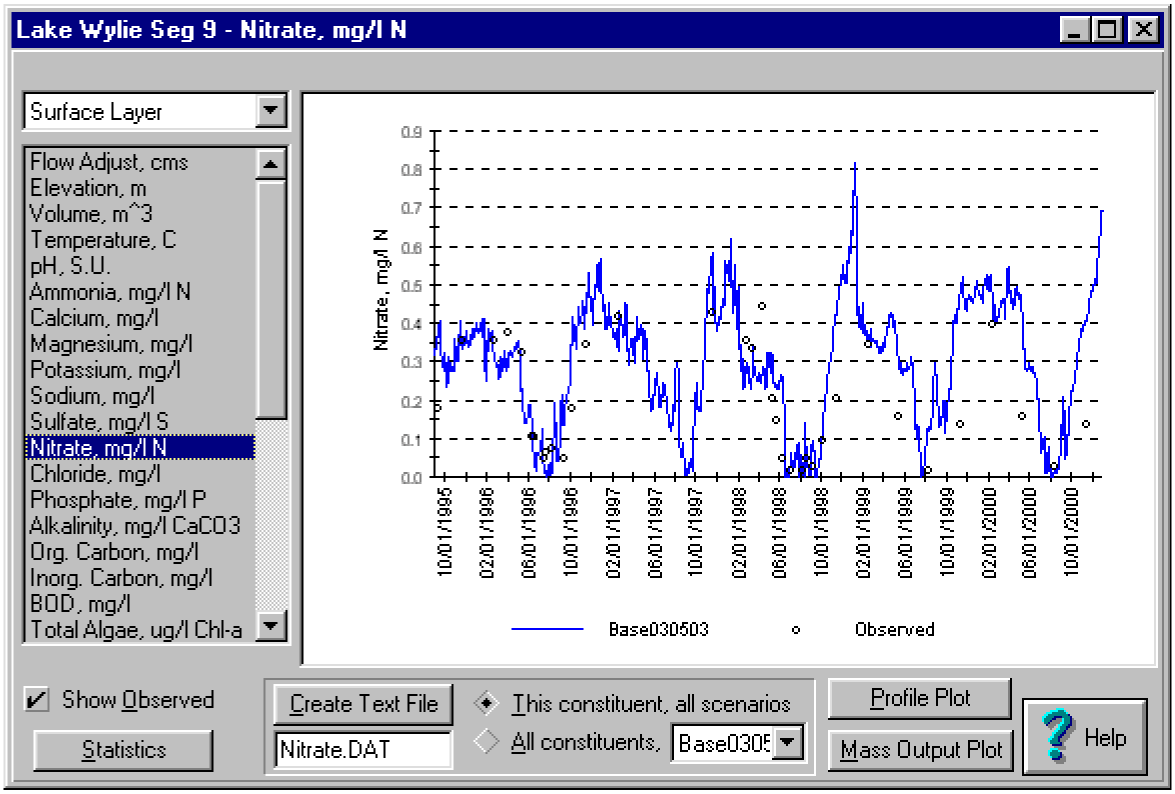


Figure 5-2
Simulated and observed NO3 at Segment 9 of Lake Wylie.

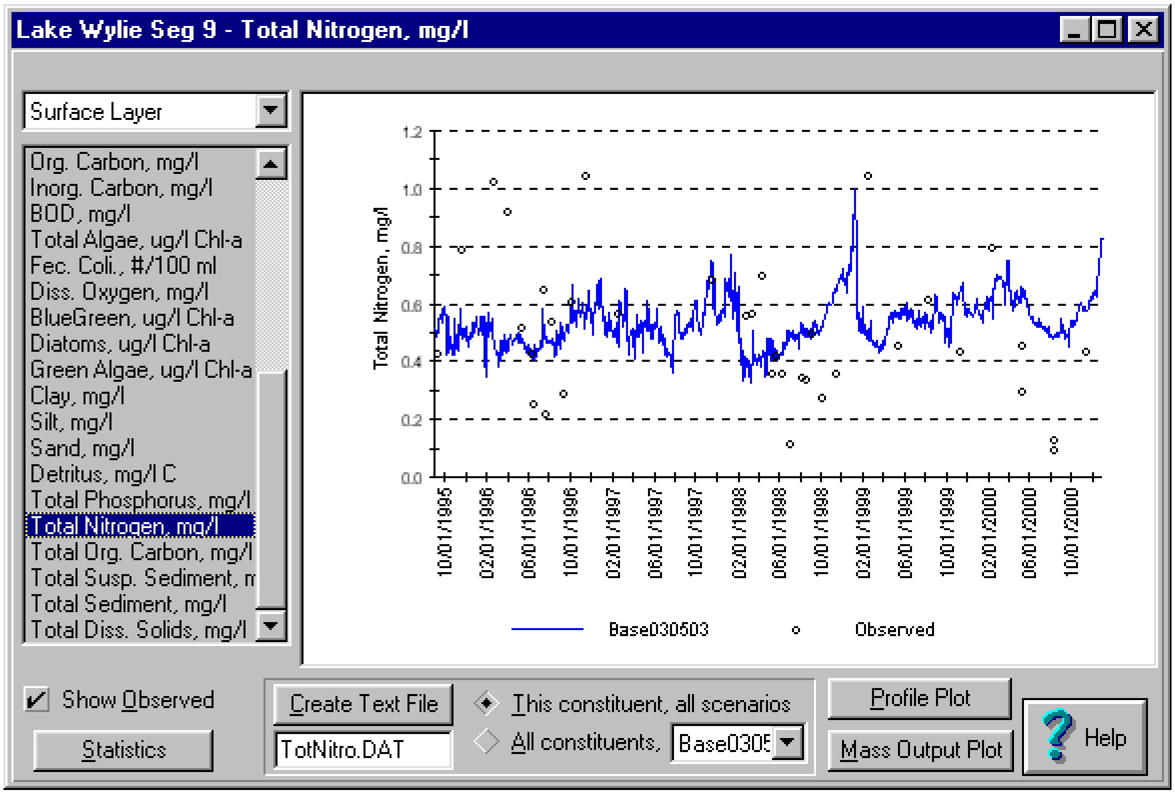


Figure 5-3
Simulated and observed TN at Segment 9 of Lake Wylie.

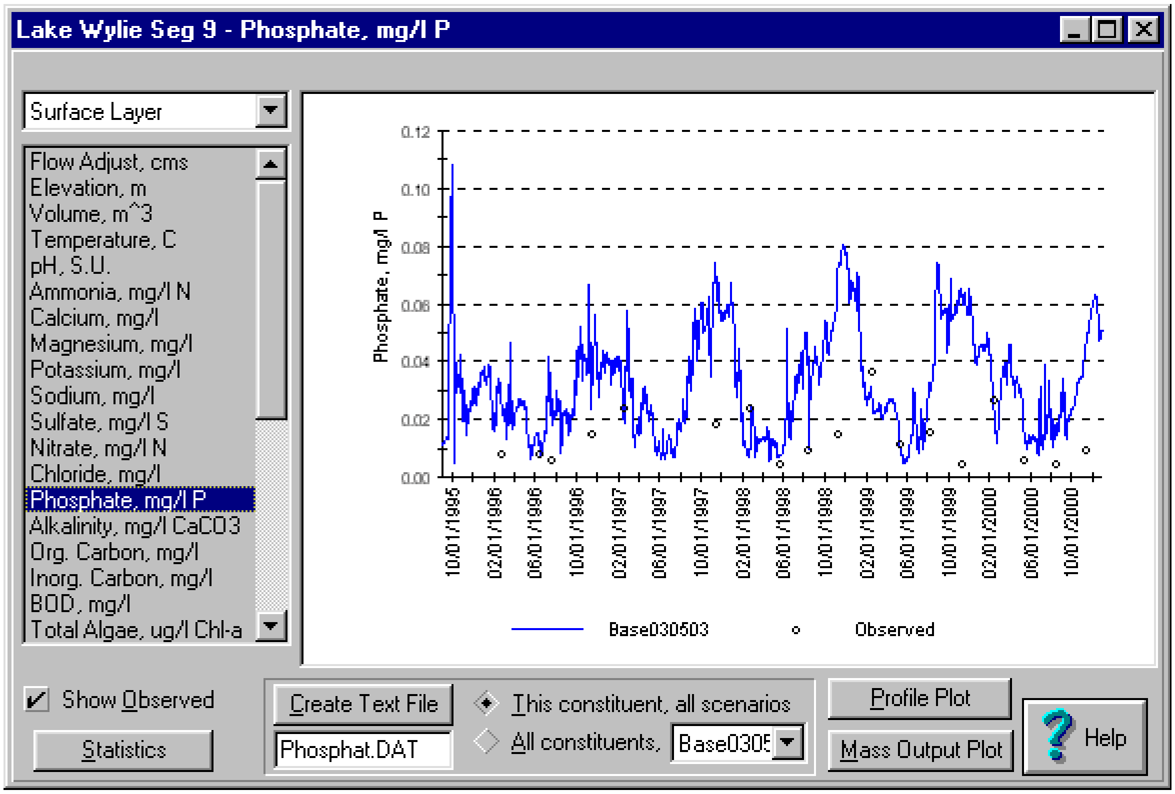


Figure 5-4
Simulated and observed PO4 at Segment 9 of Lake Wylie.

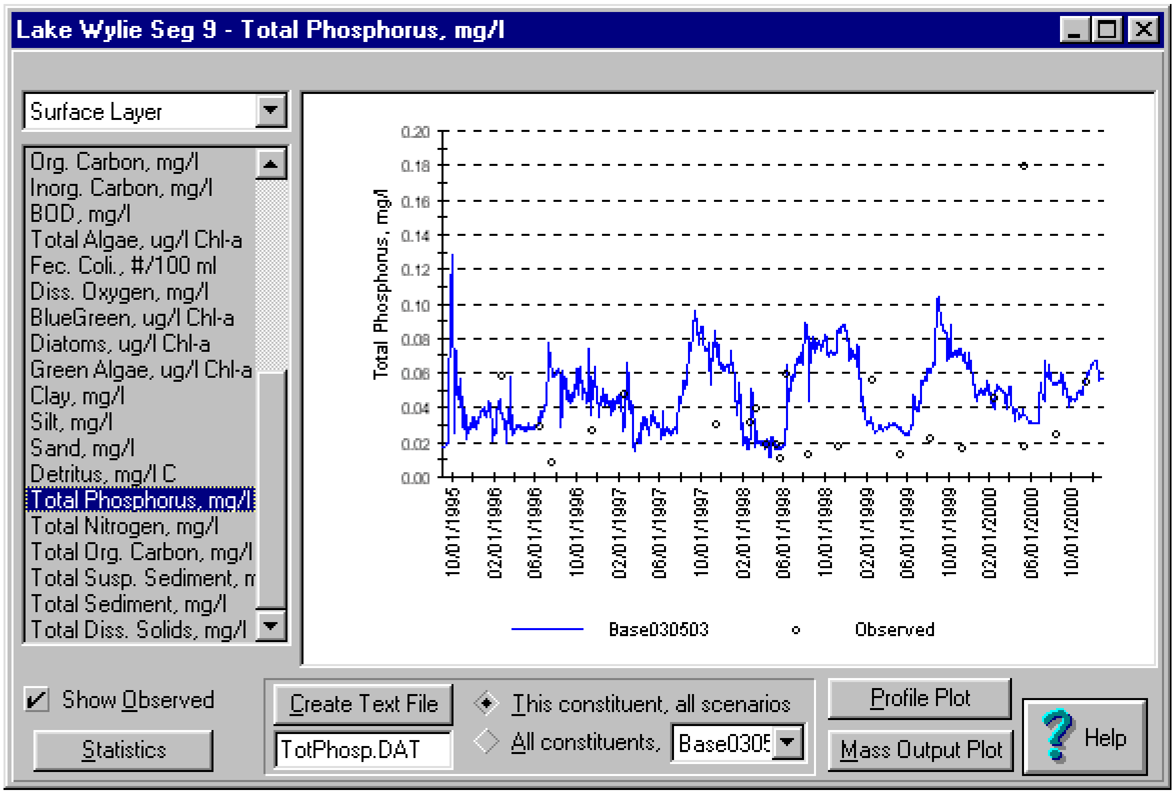


Figure 5-5
Simulated and observed TP at Segment 9 of Lake Wylie.

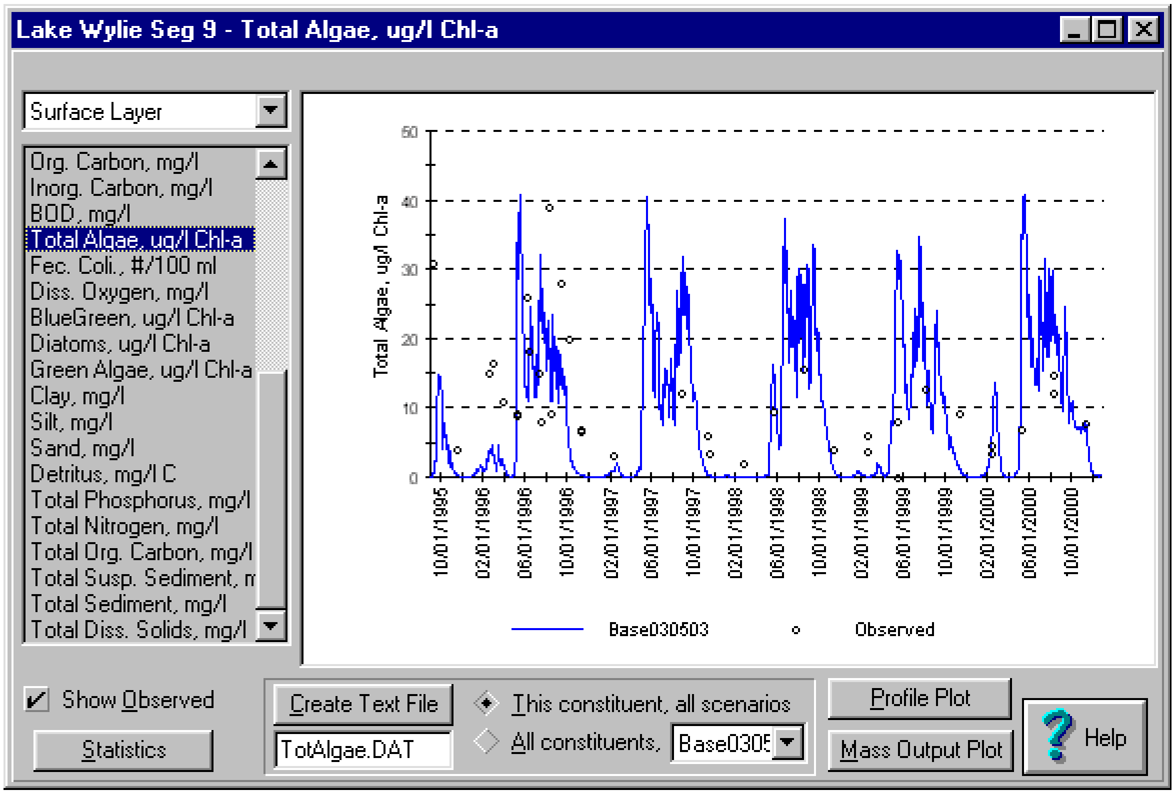


Figure 5-6
Simulated and observed total algae at Segment 9 of Lake Wylie.

LAKE WYLIE TAILWATER

The tailwater of Lake Wylie represents the reservoir releases to the downstream water body. Figure 5-7 through Figure 5-11 compare the simulated and observed concentrations of NH3, NO3, TN, PO4, and TP. The comparisons are generally very good, although the model appears to slightly over predict PO4 and TP.

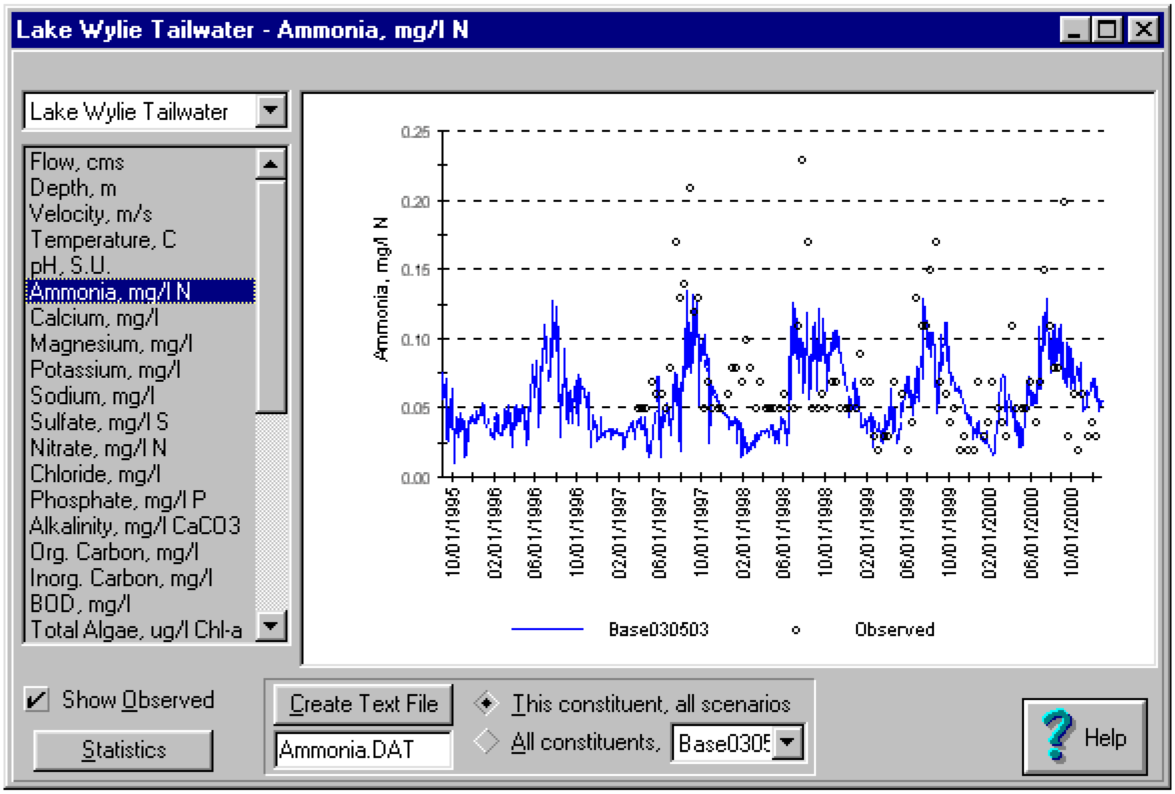


Figure 5-7
Simulated and observed NH3 at the Lake Wylie tailwater.

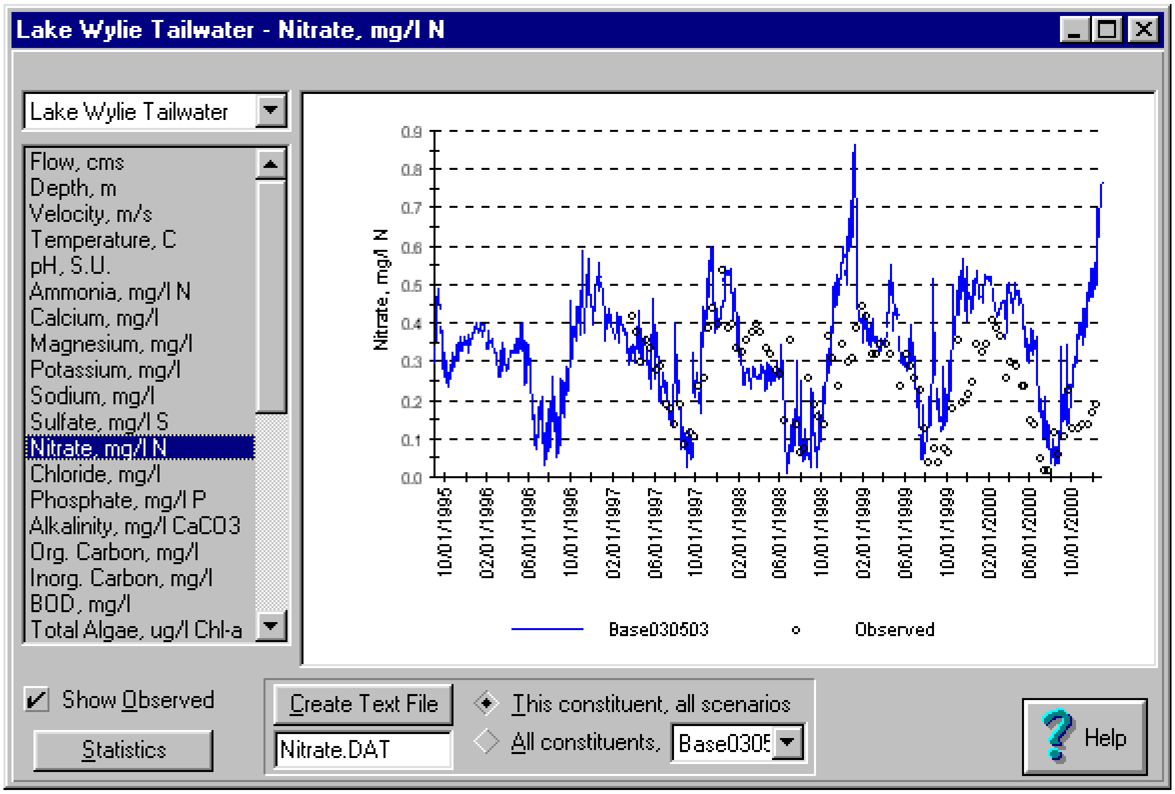


Figure 5-8
Simulated and observed NO3 at the Lake Wylie tailwater.

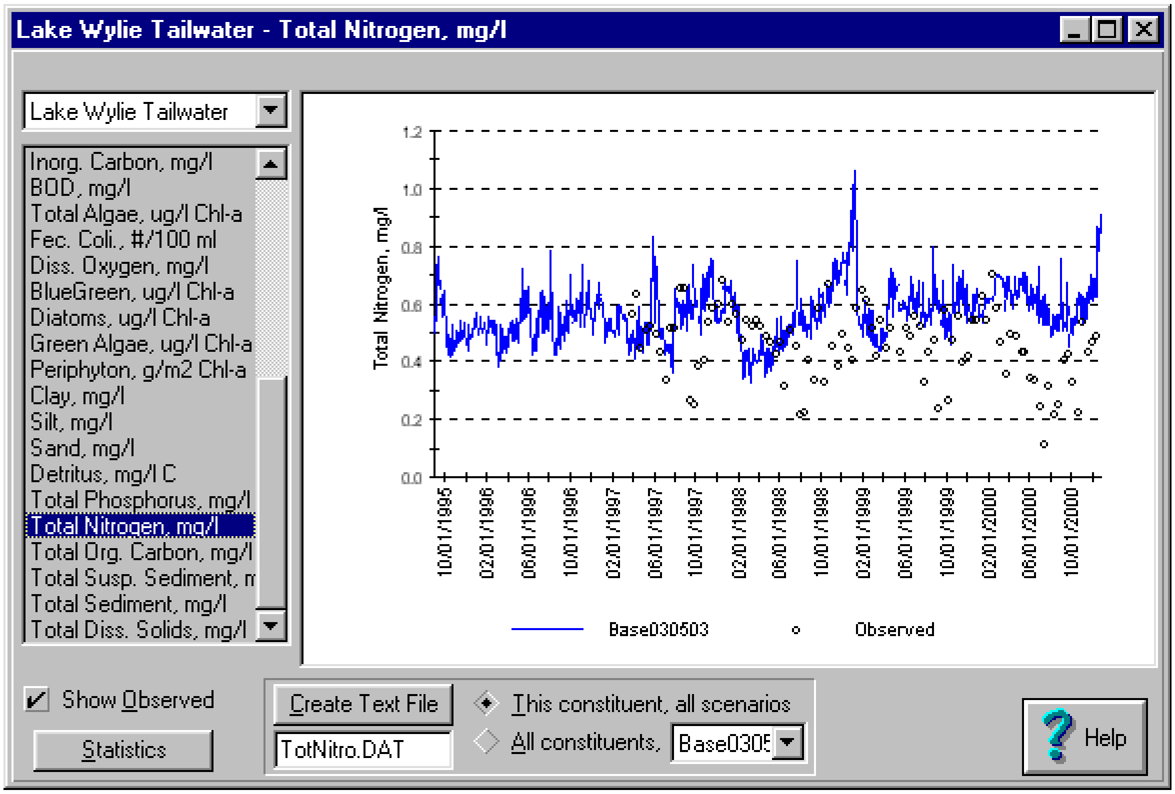


Figure 5-9
Simulated and observed TN at the Lake Wylie tailwater.

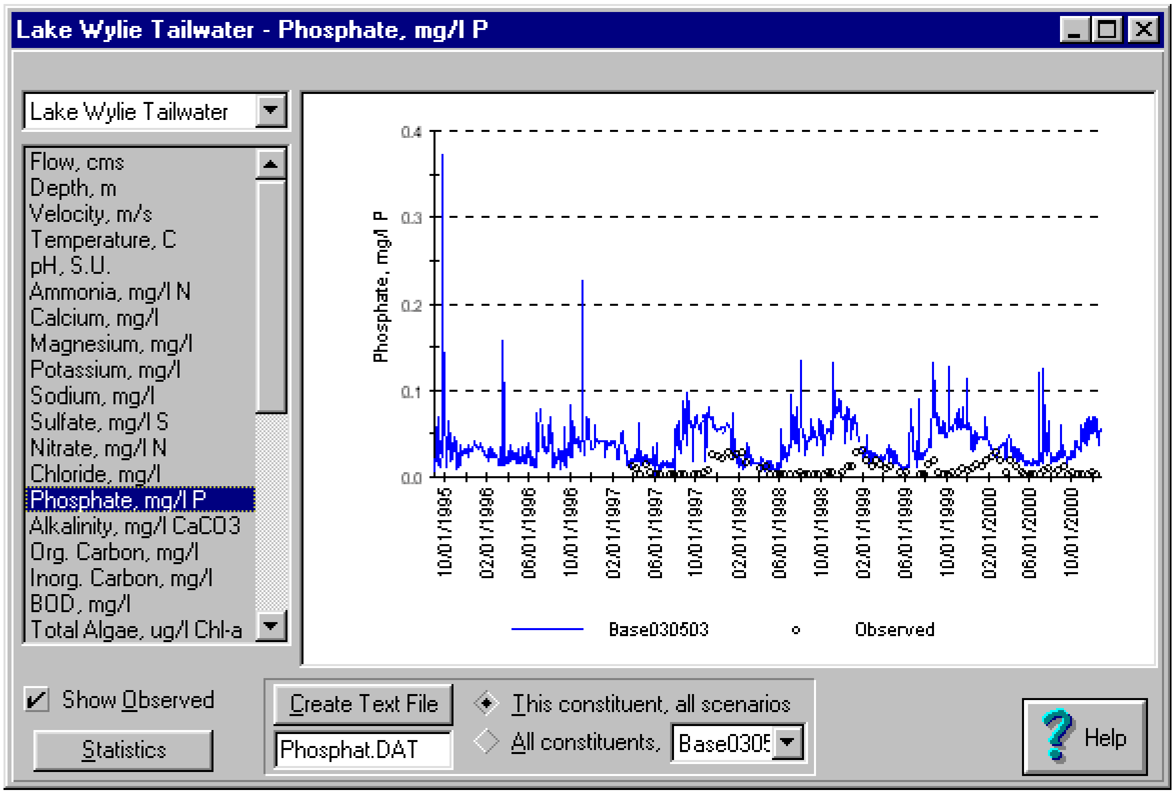


Figure 5-10
Simulated and observed PO4 at the Lake Wylie tailwater.

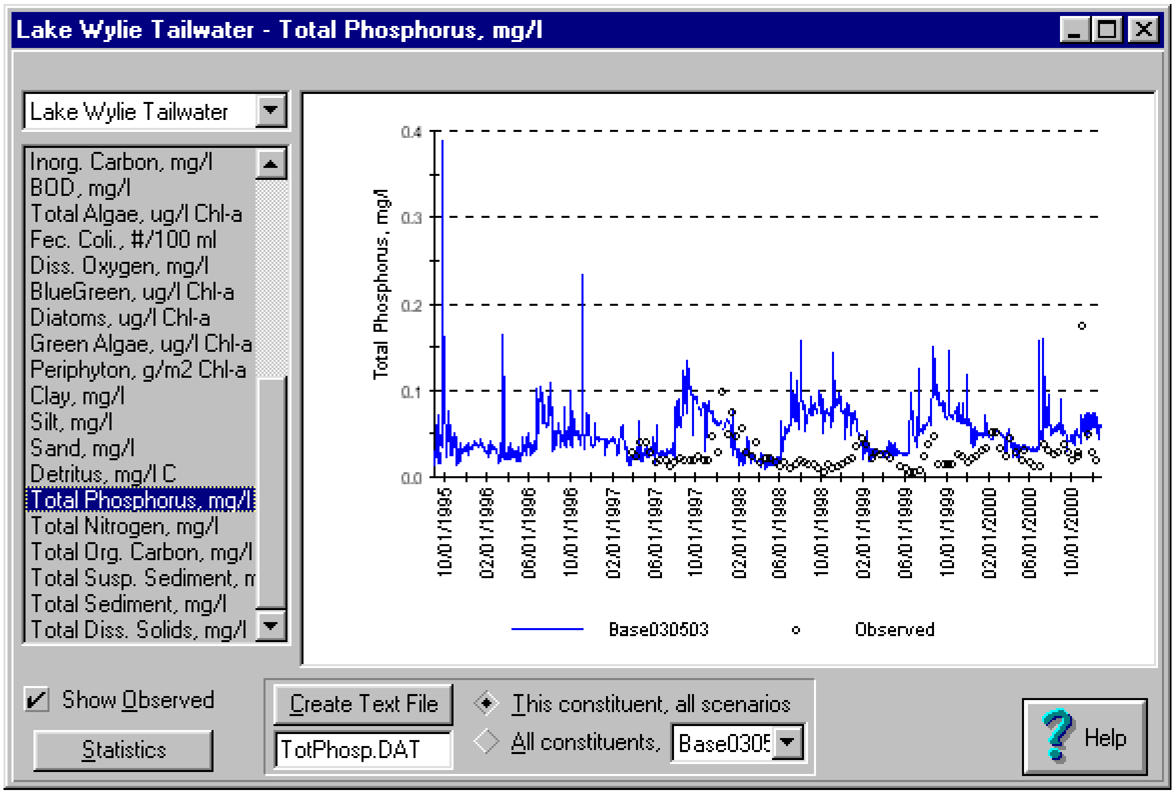


Figure 5-11
Simulated and observed TP at the Lake Wylie tailwater.

SUGAR CREEK

Sugar Creek is a tributary to Fishing Creek Reservoir. The Sugar Creek Watershed includes the Charlotte metropolitan area of Mecklenburg County as shown in Figure 5-12.

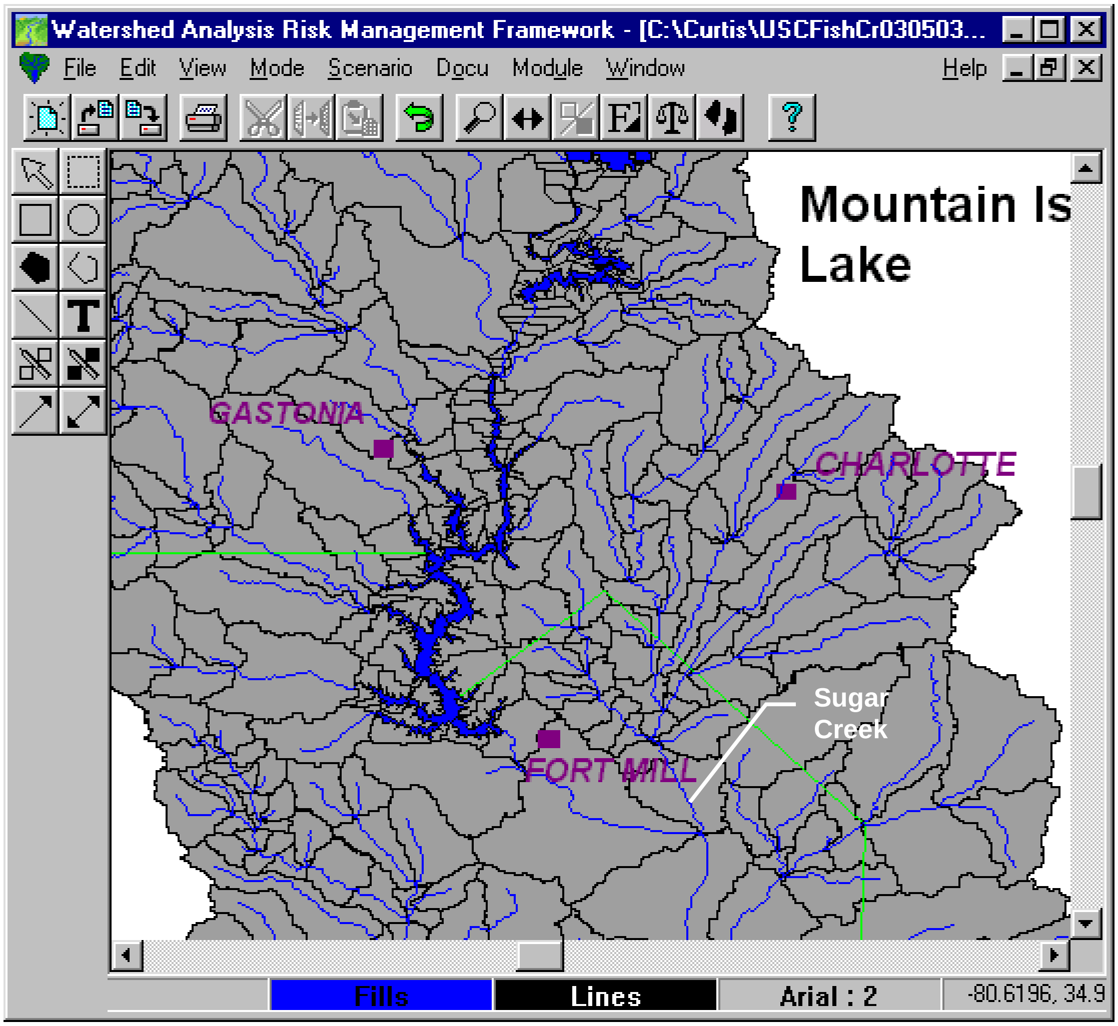


Figure 5-12
Map of Sugar Creek Subwatershed.

Results of Sugar Creek simulations are shown near Fort Mill, not far from the mouth of the creek. Figure 5-13 compares simulated and observed NH3. Figure 5-14 shows the simulation results of NO3 for Sugar Creek, and Figure 5-15 shows the comparison of TN. Figure 5-16 plots TP results for the creek.

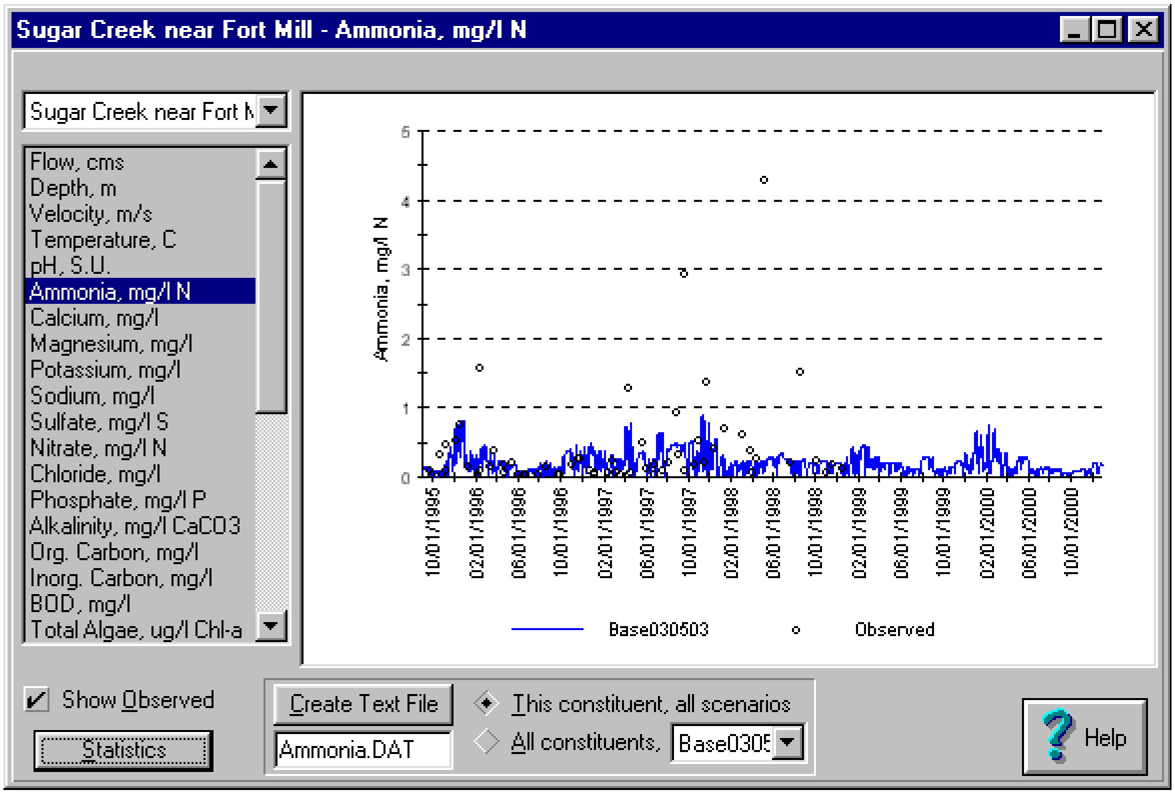


Figure 5-13
Simulated and observed NH3 in Sugar Creek Near Fort Mill.

From these comparisons, WARMF appears to under predict a few of the highest observed spikes in ammonia concentrations in Sugar Creek. The under prediction of these spikes is possibly a result of the point-source data to the creek that is specified in the model on a constant monthly basis. A few large point sources in the subwatershed contribute significant nutrient load, including ammonia loading, to the creek. A daily specification of loading may improve the simulation, but effluent is monitored only monthly. In general, however, the average simulated NH3 concentration appears very close to the average observed values. The same is true for NO3, TN, and TP in the remaining plots.

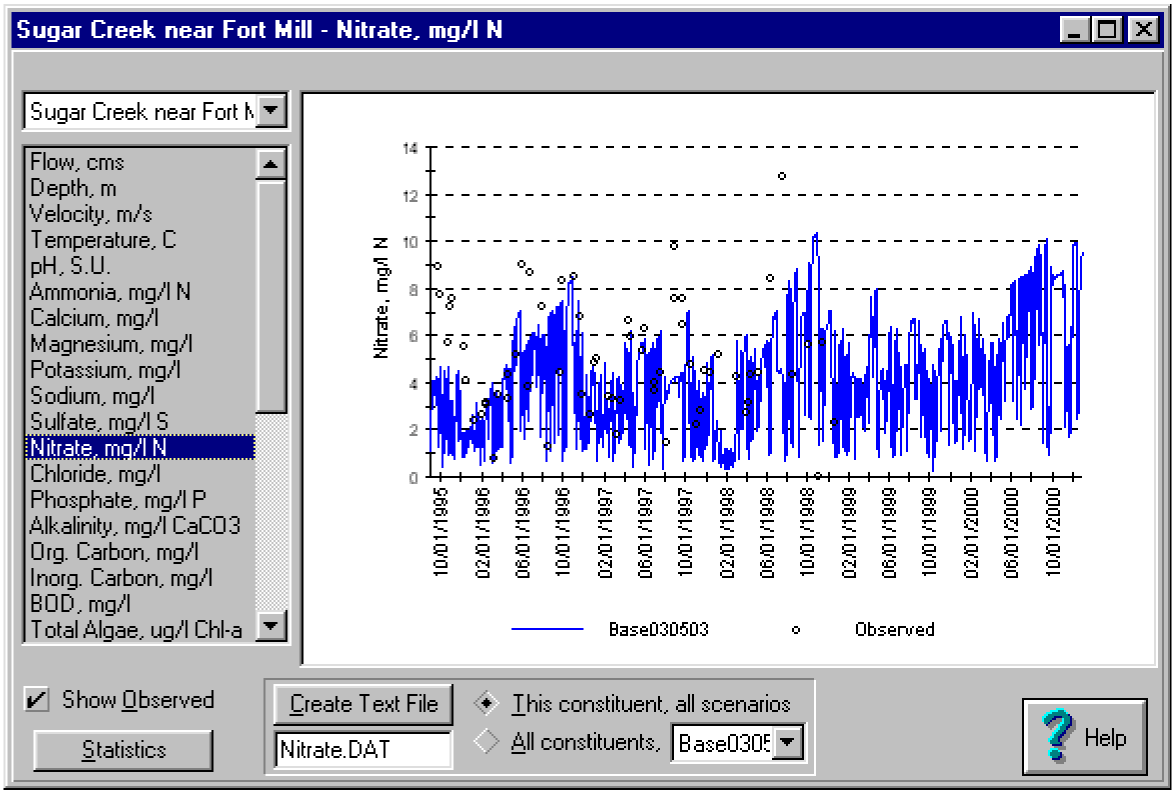


Figure 5-14
Simulated and observed NO3 in Sugar Creek Near Fort Mill.

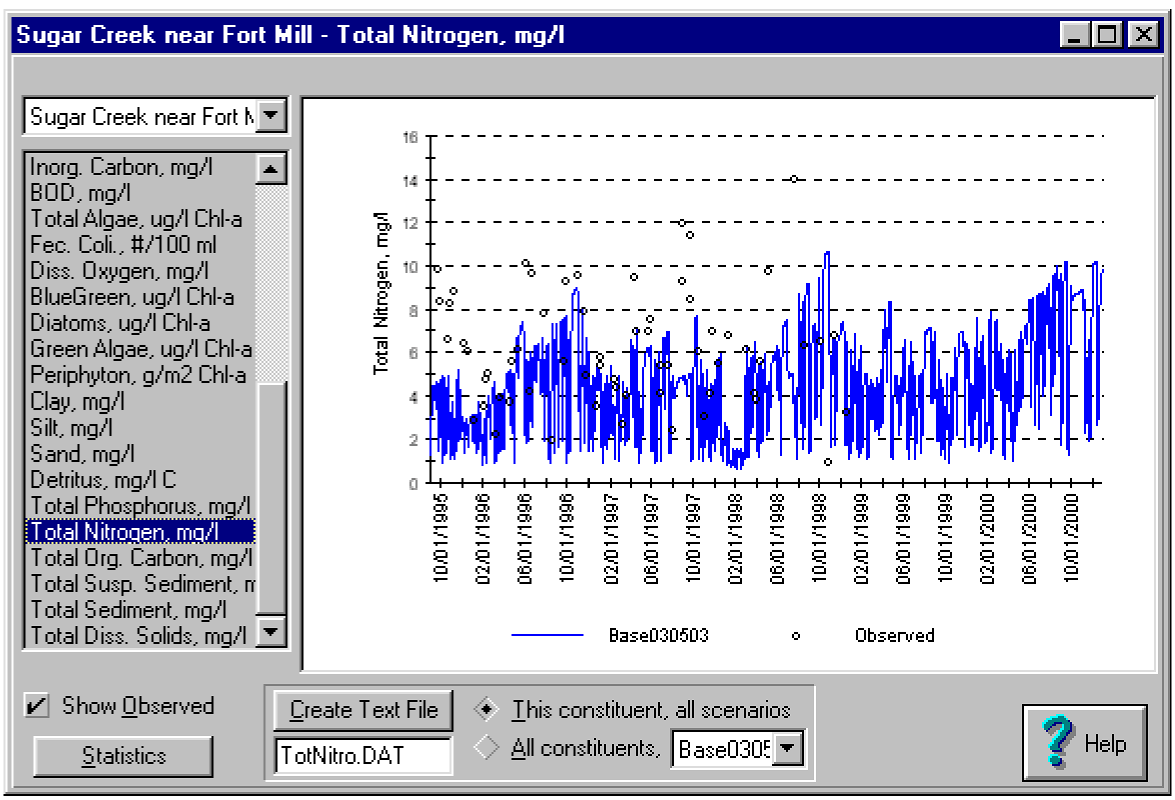


Figure 5-15
Simulated and observed TN in Sugar Creek Near Fort Mill.

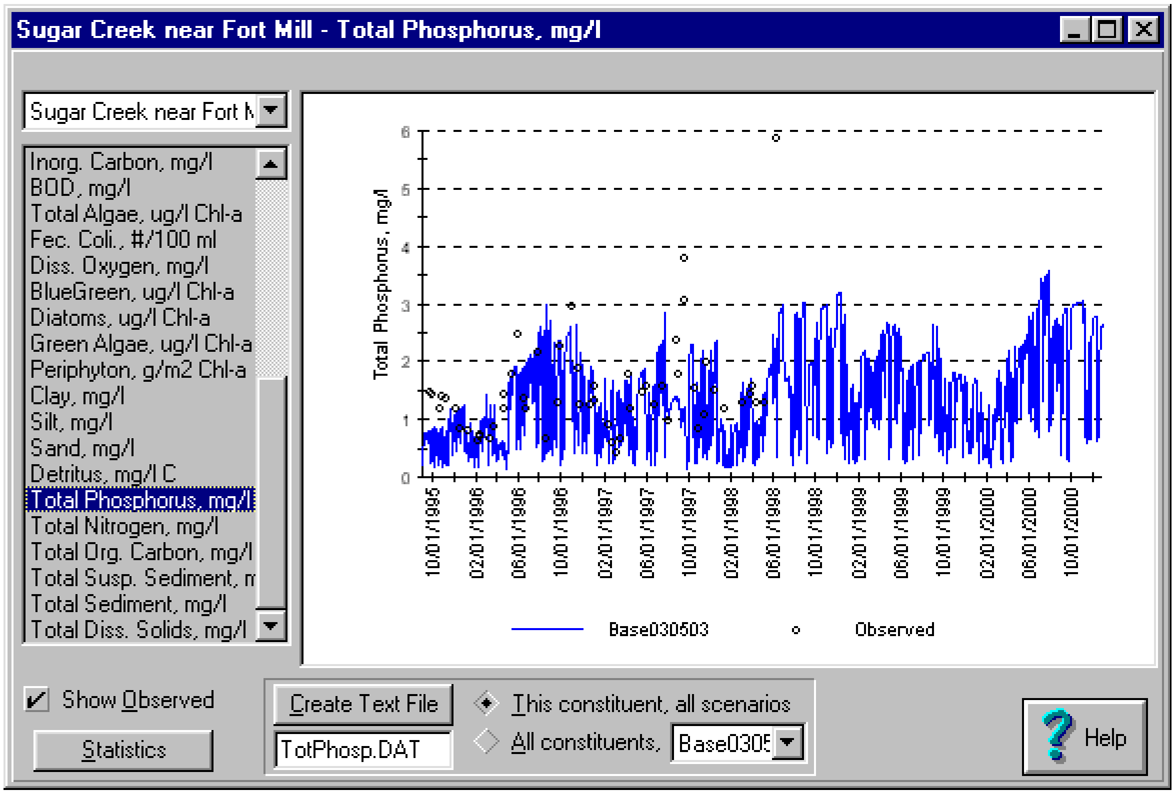


Figure 5-16
Simulated and observed TP in Sugar Creek Near Fort Mill.

FISHING CREEK

The simulation results for Fishing Creek are discussed for stations S 46-163 and SC 223. Figure 5-17 shows the locations of these two stations. The City of York treatment plant discharges its effluent at a few stream segments upstream of station S 46-163. Thus, the water quality of both S 46-163 and SC 223 stations are affected by the point source discharge.

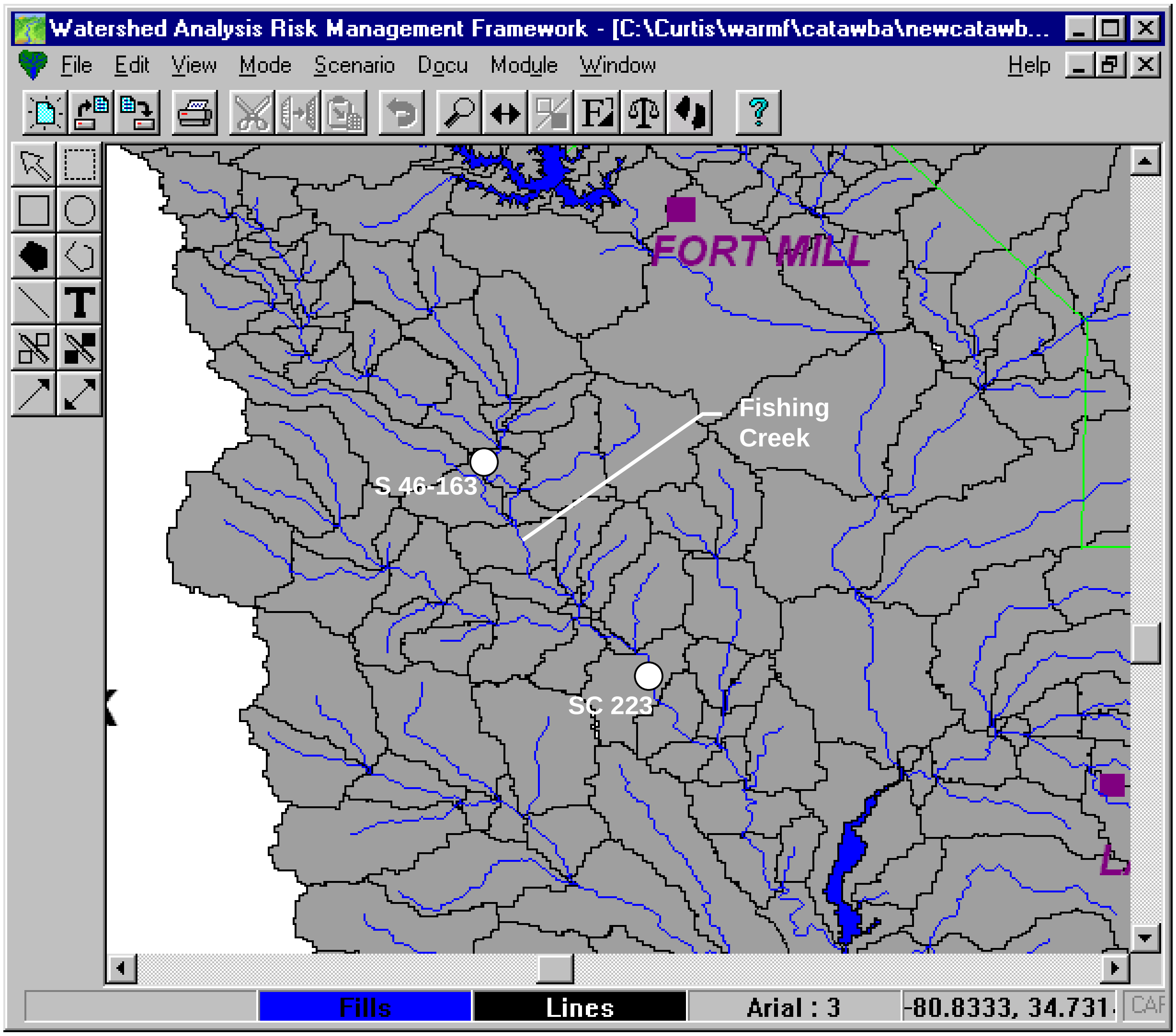


Figure 5-17
Locations where simulated and observed data are shown in the Fishing Creek Watershed.

For station S 46-163, Figure 5-18 shows the results for NH3. Figure 5-19 shows the results for NO3, and Figure 5-20 shows the results for TN. TP output is shown in Figure 5-21.

These comparisons indicate that WARMF predict the concentrations of NH3, NO3, TN and TP within the ranges of observed data. However, there are spikes of high observed values not simulated by the model. The model simulated clear seasonal variations of NO3 and TN in the observed data. These are caused by the hydrology. As shown in Figure 4-1 and Figure 4-2, the simulated flows are low when the simulated NO3 and TN concentrations are high. The City of York has a constant discharge of their effluent. A higher flow in the receiving water provides dilution and thus lower concentrations of nutrients.

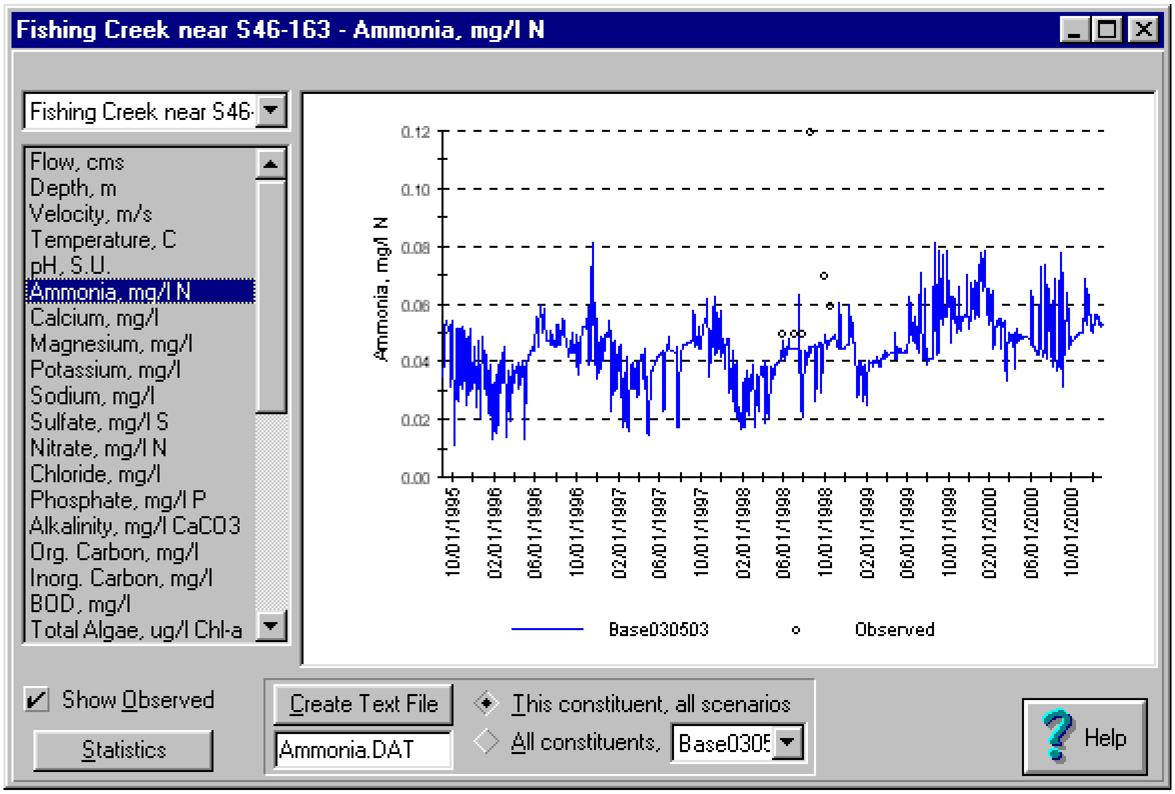


Figure 5-18
Simulated and observed NH3 in Fishing Creek at station S 46-163.

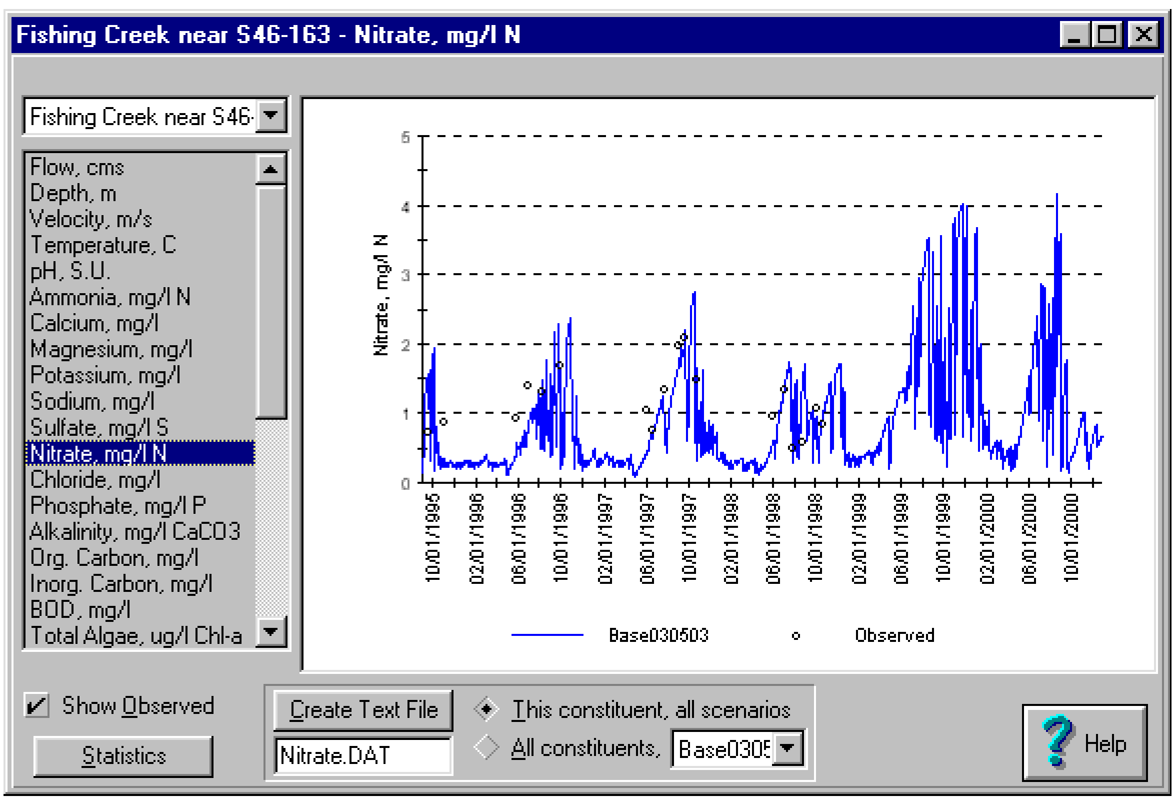


Figure 5-19
Simulated and observed NO3 in Fishing Creek at station S 46-163.

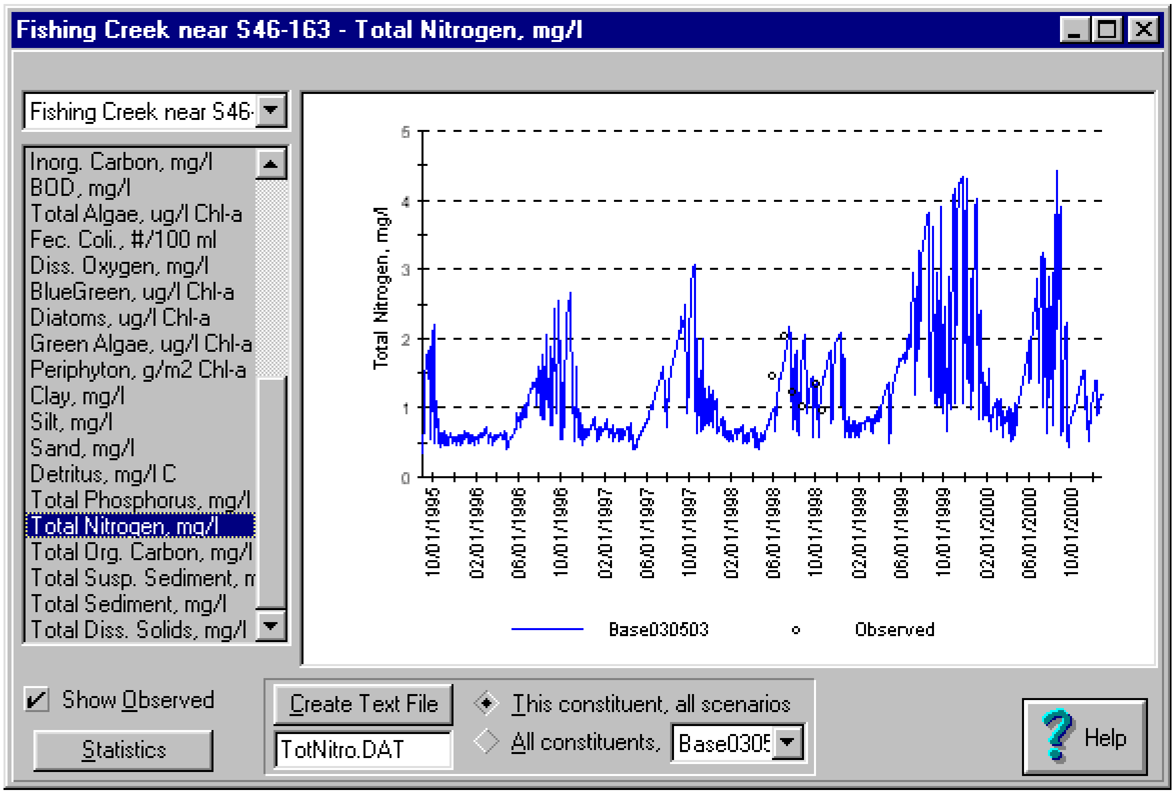


Figure 5-20
Simulated and observed TN in Fishing Creek at station S 46-163.

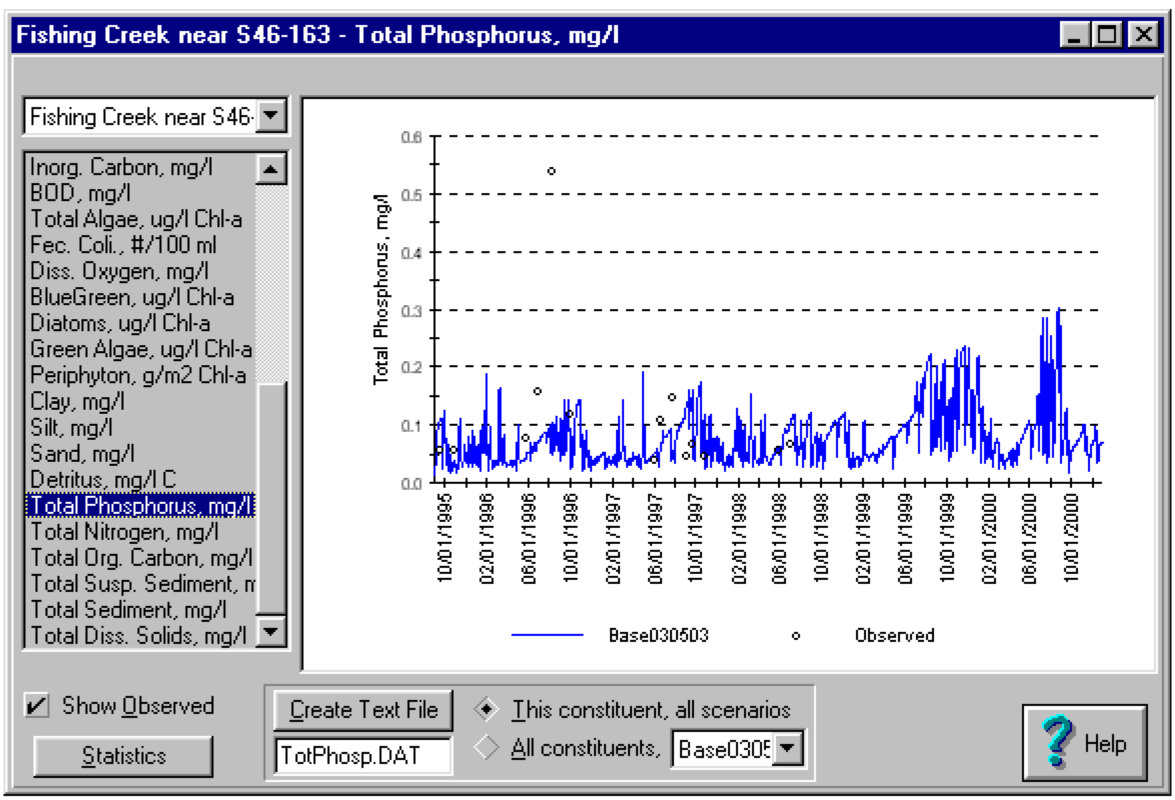


Figure 5-21
Simulated and observed TP in Fishing Creek at station S 46-163.

For station SC 223, Figure 5-22 shows the results for NH3. Figure 5-23 shows the results for NO3. Figure 5-24 shows the results for TN. Figure 5-25 shows the results for TP.

These comparisons indicate that WARMF has under predicted NH3 concentrations of NH3. The predictions of NO3, TN and TP are within the ranges of observed data. Some spikes of high observed values are not simulated by the model.

The seasonal variations of NO3 and TN observed at station S 46-163 are still apparent at station SC 223. These variations are flow related as discussed earlier. The impact of the point source discharge of the City of York appears to have been attenuated between S 46-163 and SC 223.

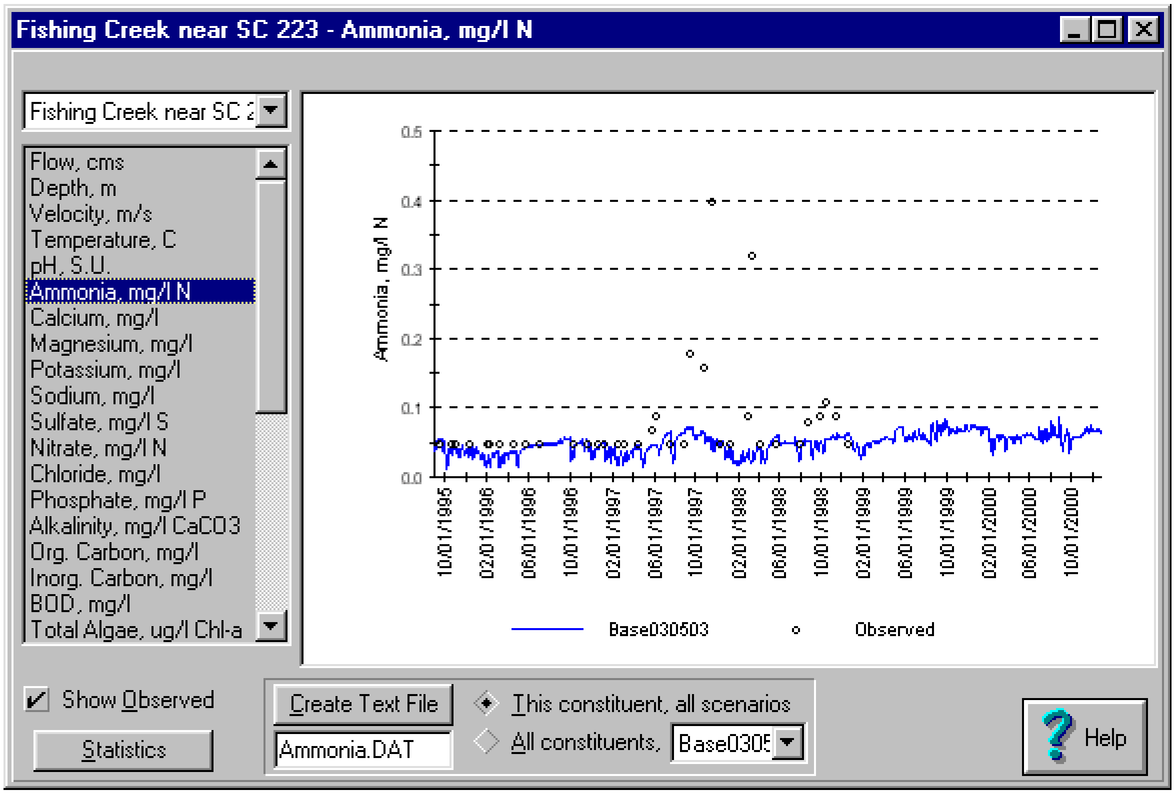


Figure 5-22
Simulated and observed NH3 in Fishing Creek at station SC 223.

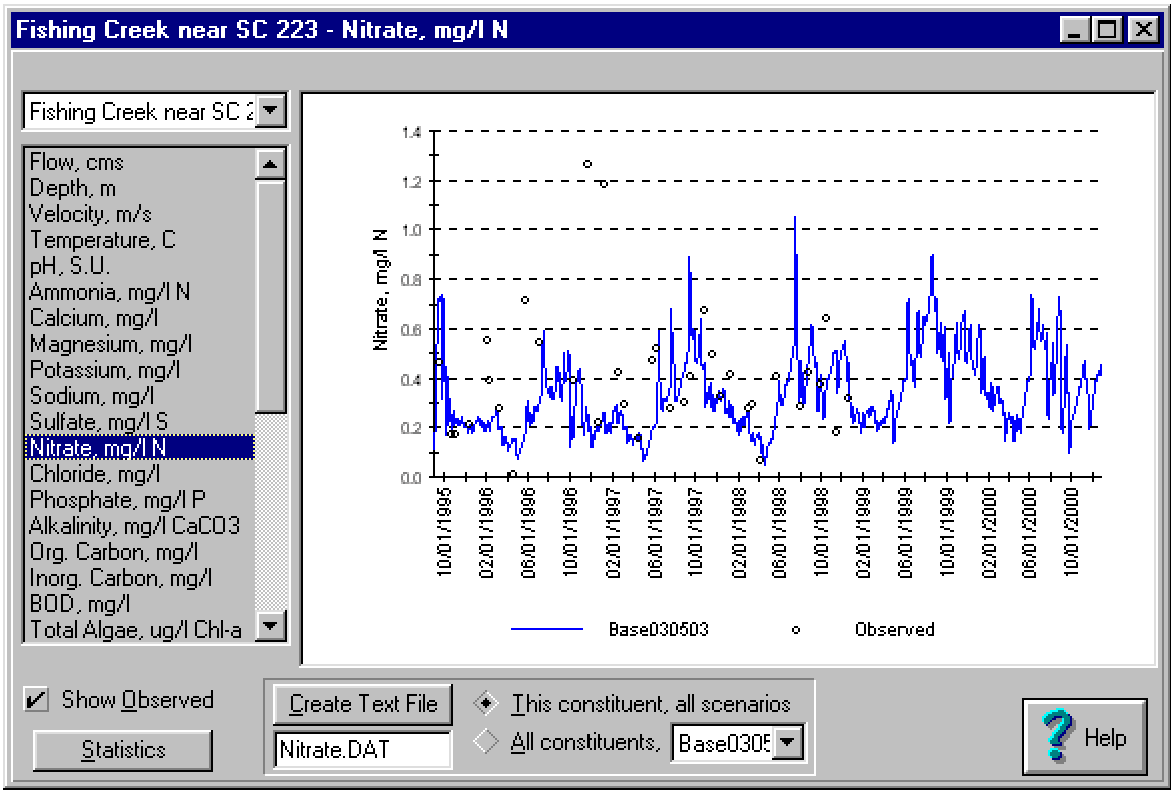


Figure 5-23
Simulated and observed NO3 in Fishing Creek at station SC 223.

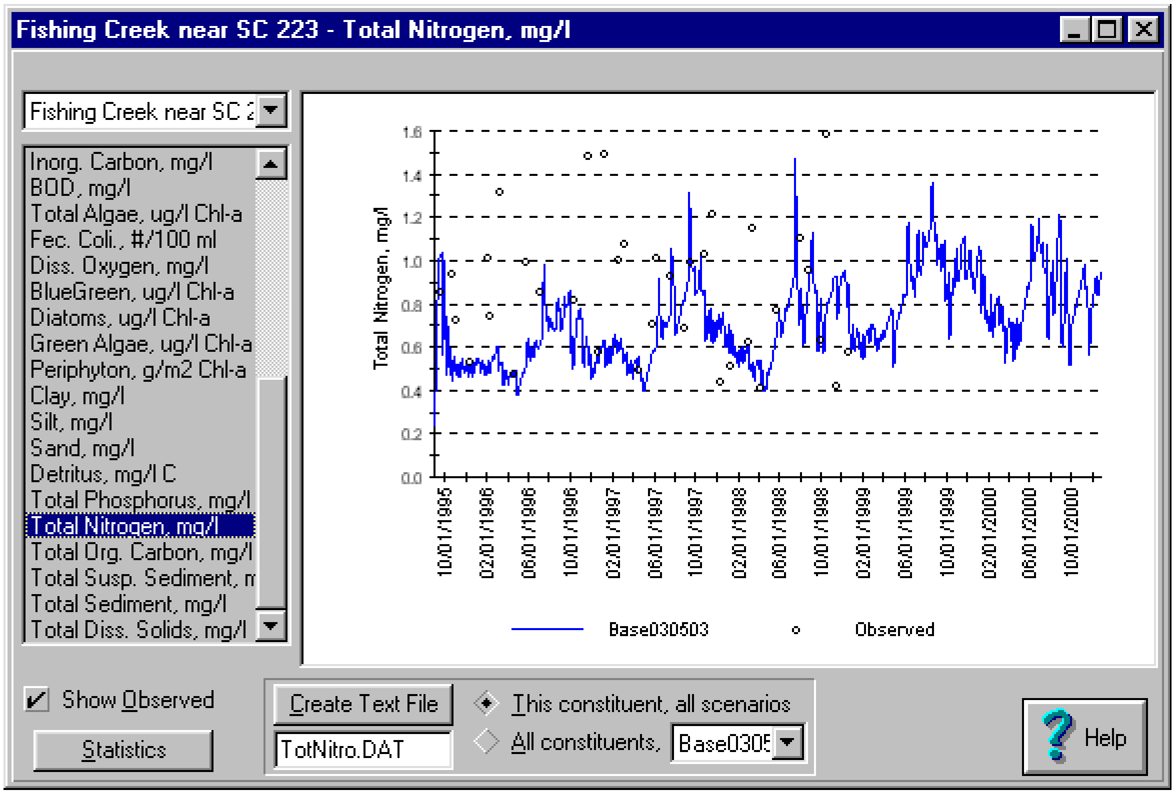


Figure 5-24
Simulated and observed TN in Fishing Creek at station SC 223.

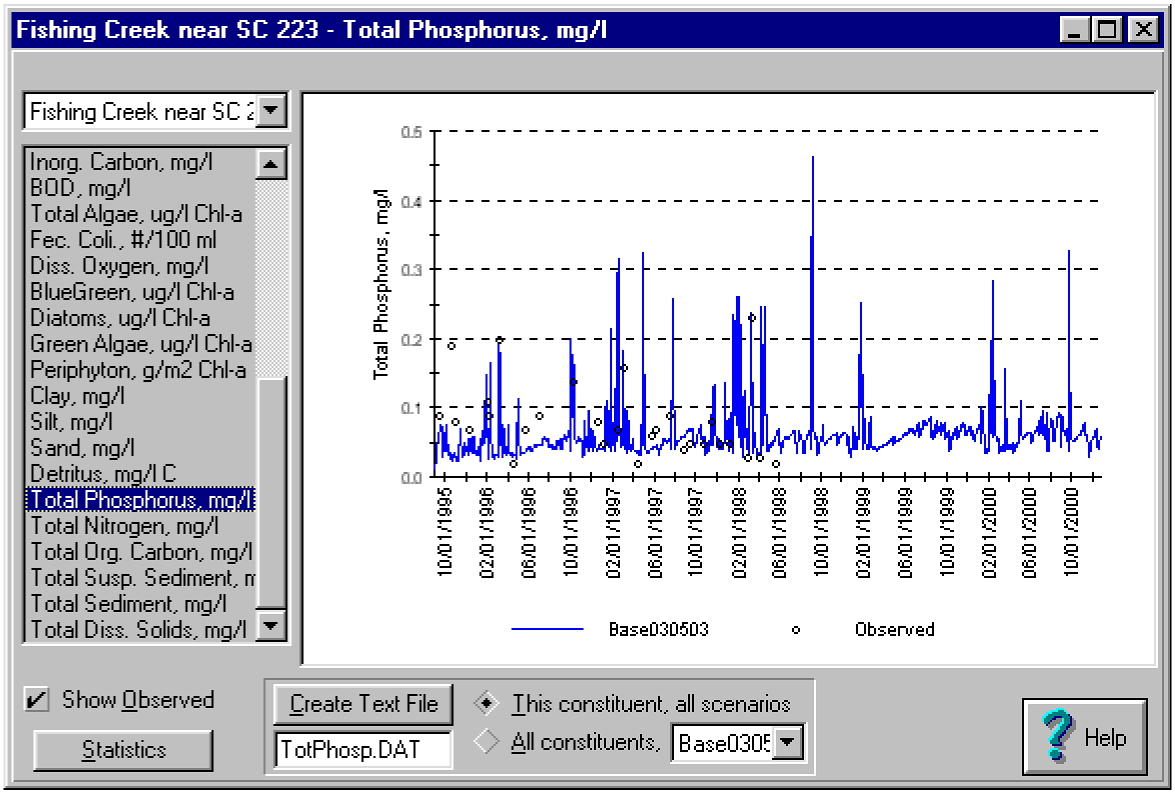


Figure 5-25
Simulated and observed TP in Fishing Creek at station SC 223.

FISHING CREEK RESERVOIR

Figure 5-26 shows the locations of Fishing Creek Reservoir, Great Falls Reservoir and Cedar Creek Reservoir. The tailrace of Fishing Creek Reservoir is the forebay of Great Falls Reservoir. The Great Falls tailrace is also the Cedar Creek Reservoir forebay. In the following sections, the model results will be discussed for these reservoirs in sequence.

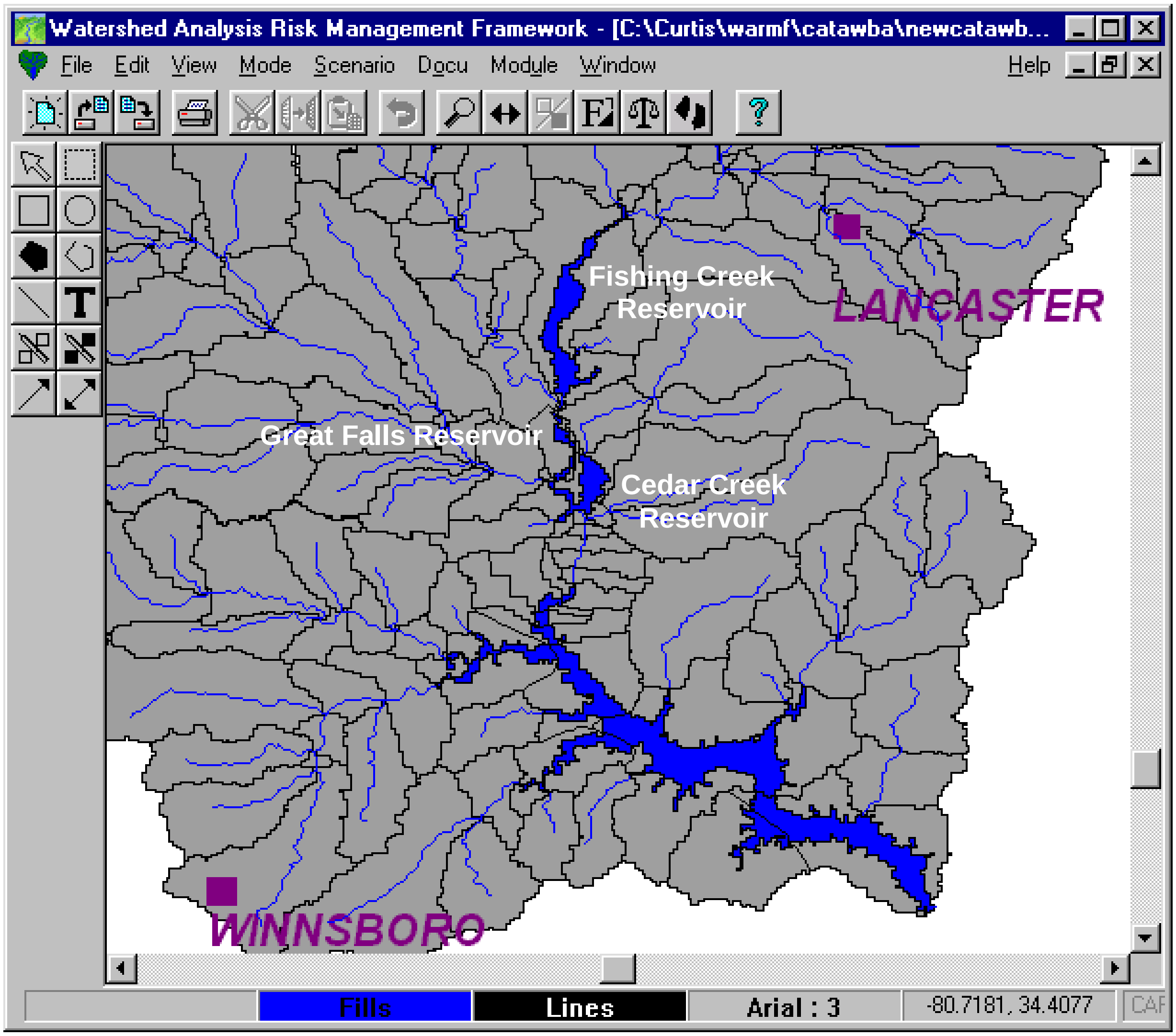


Figure 5-26
Locations of Fishing Creek, Great Falls and Cedar Creek Reservoirs.

Figure 5-27 through Figure 5-32 present the simulation results for NH3, NO3, TN, PO4, TP, and total algae, respectively. All these comparisons are for the surface water of the reservoir, where most of the algal growth occurs.

In general, the model simulates nutrients and algae in well. Though the model under-predicts some the peak levels of observed NH3, it tracks mean NH3 levels as well as NO3 and TN fairly well. The model also captures the general trend and magnitudes of observed PO4 and TP concentrations. Simulated algae levels also follow observed data well, though the spring diatom bloom is under-predicted in some years (Figure 5-32).

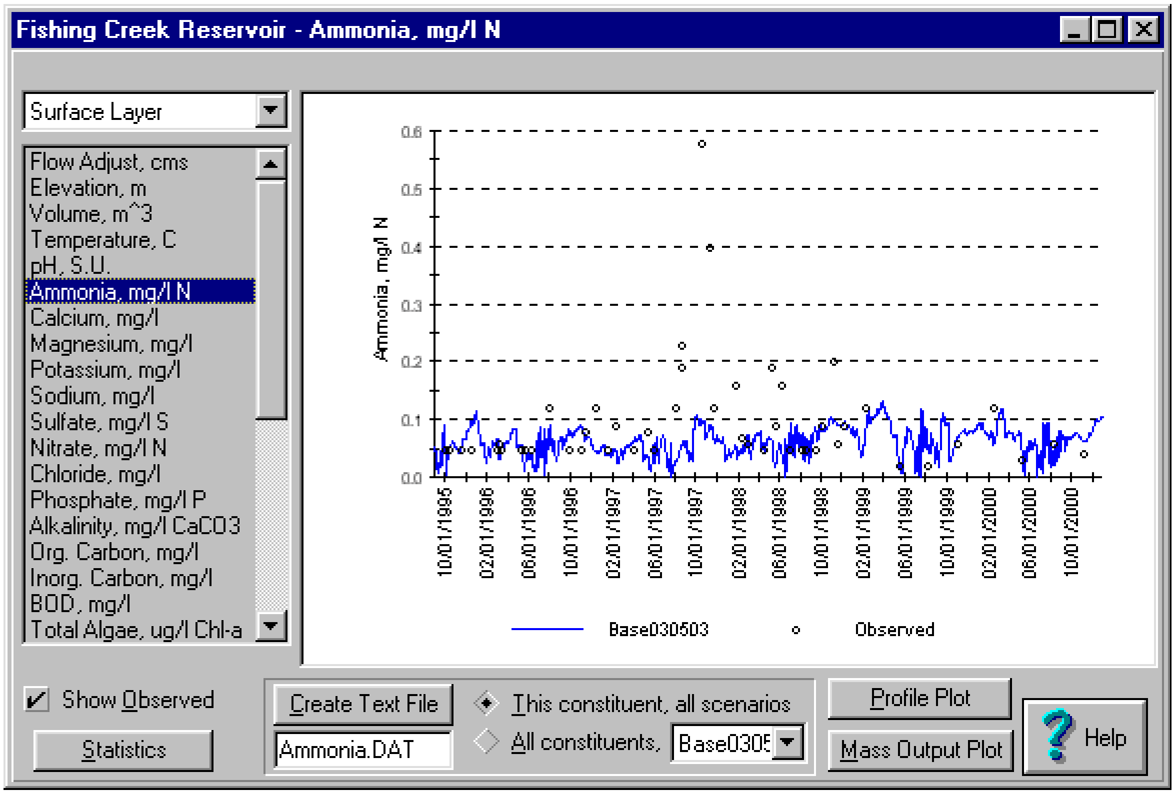


Figure 5-27
Simulated and observed NH3 in Fishing Creek Reservoir.

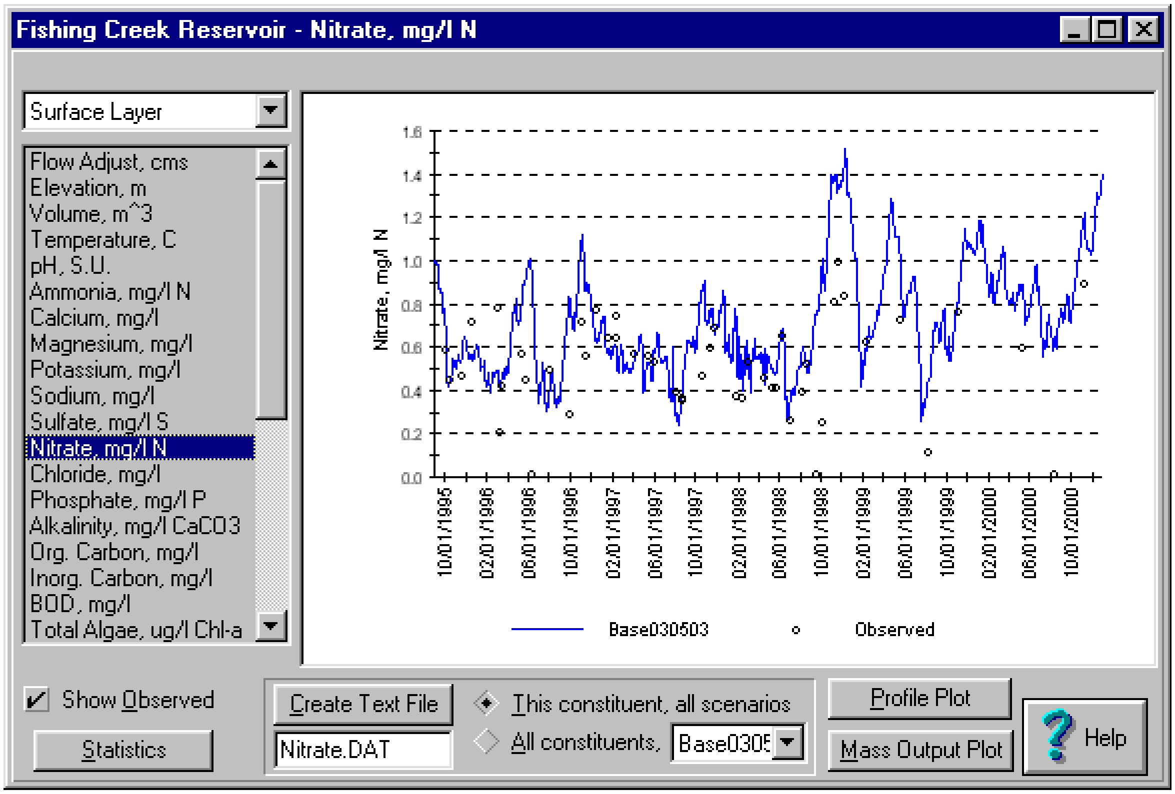


Figure 5-28
Simulated and observed NO3 in Fishing Creek Reservoir.

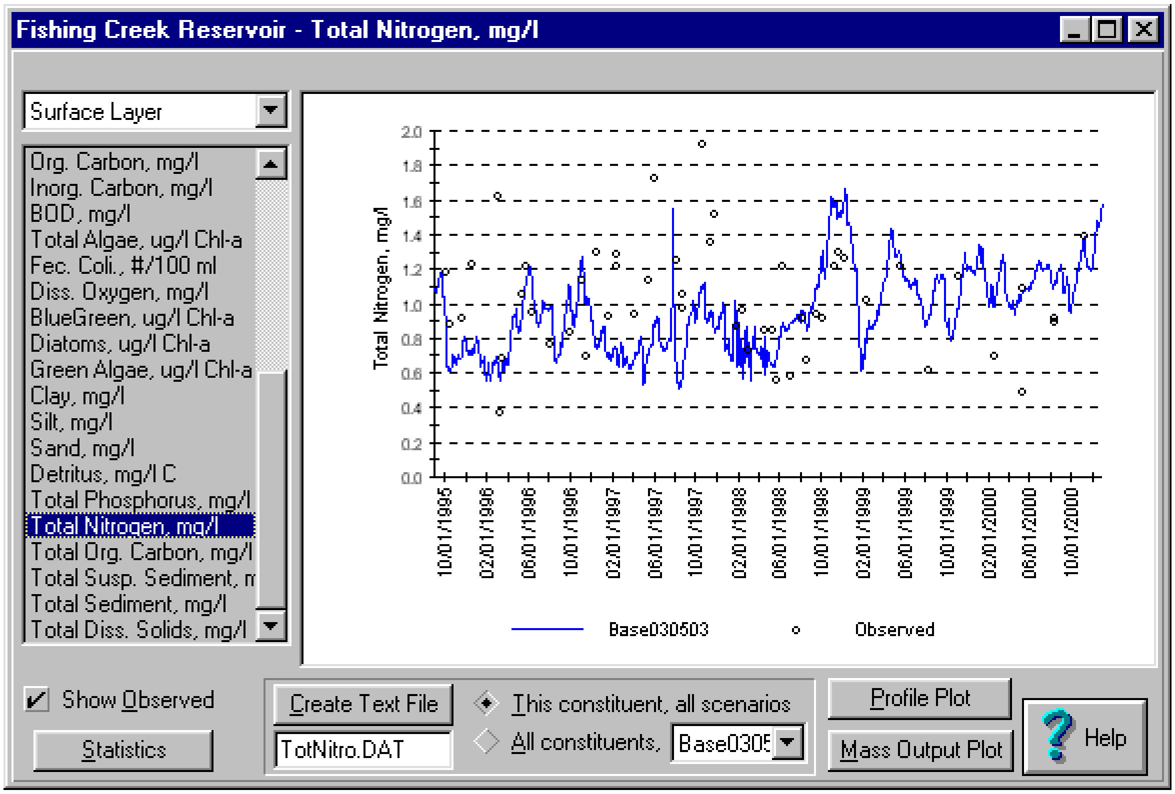


Figure 5-29
Simulated and observed TN in Fishing Creek Reservoir.

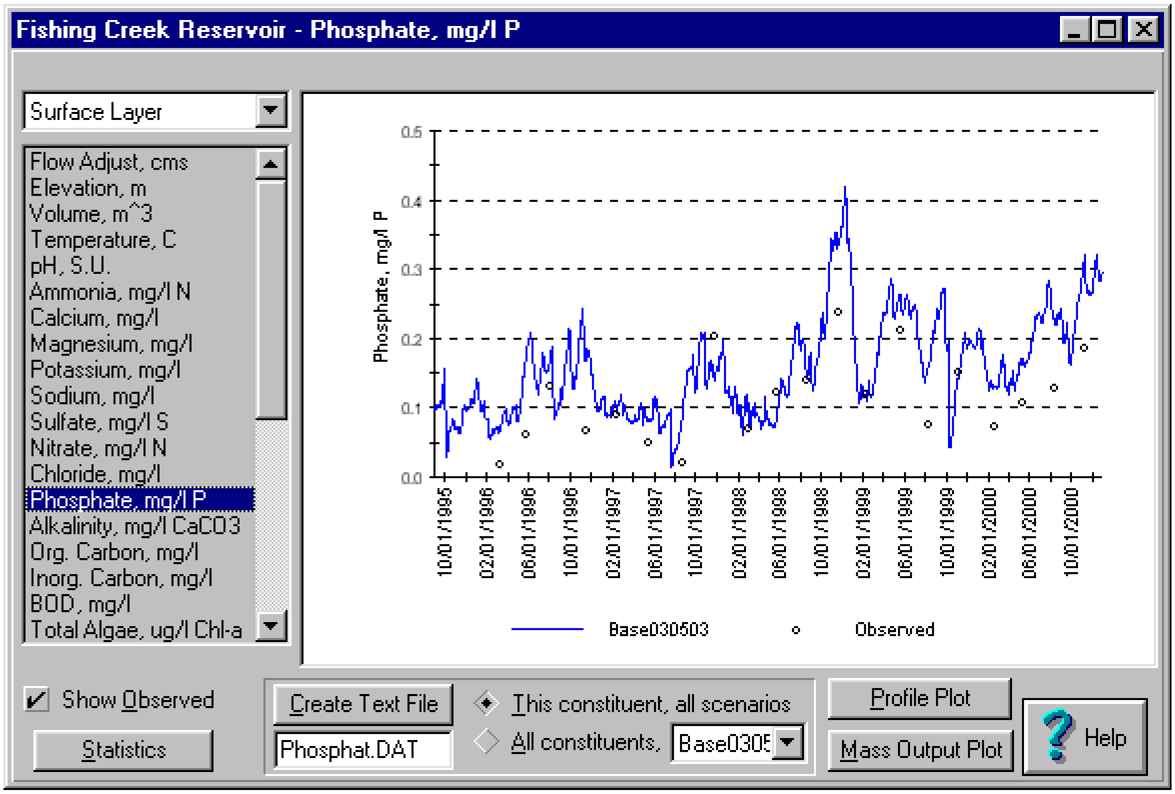


Figure 5-30
Simulated and observed PO4 in Fishing Creek Reservoir.

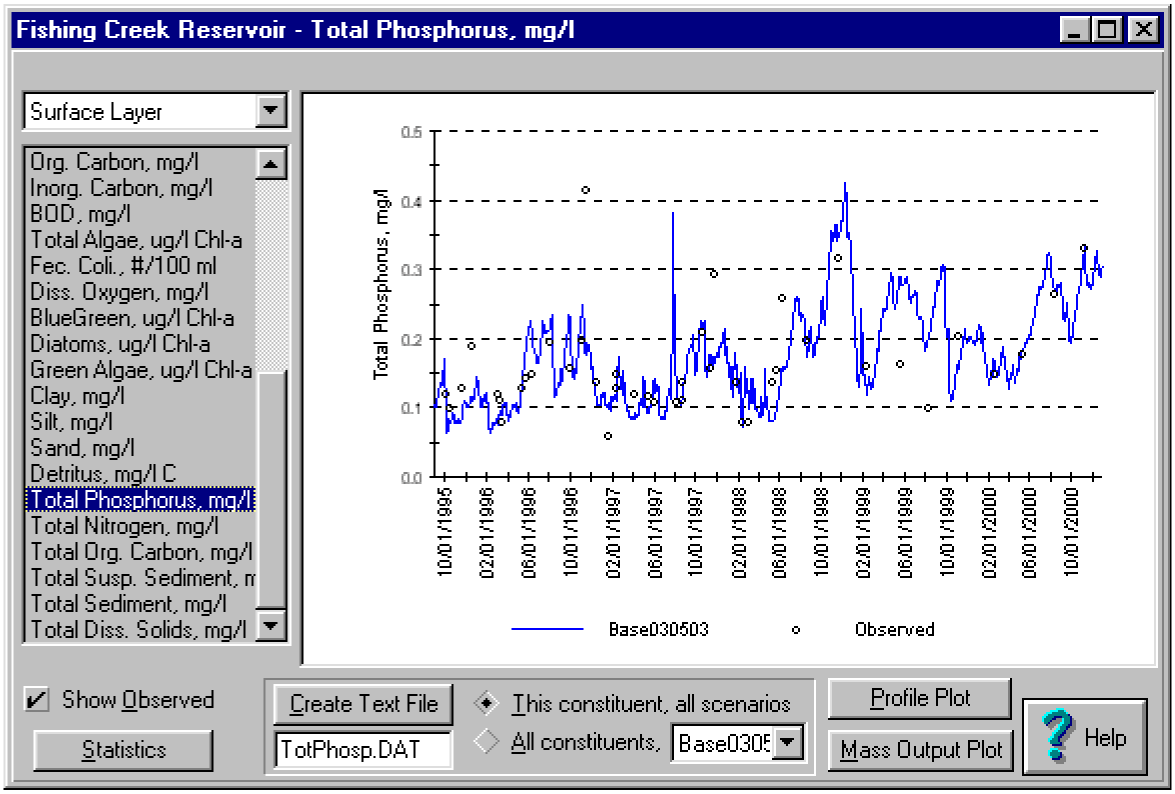


Figure 5-31
Simulated and observed TP in Fishing Creek Reservoir.

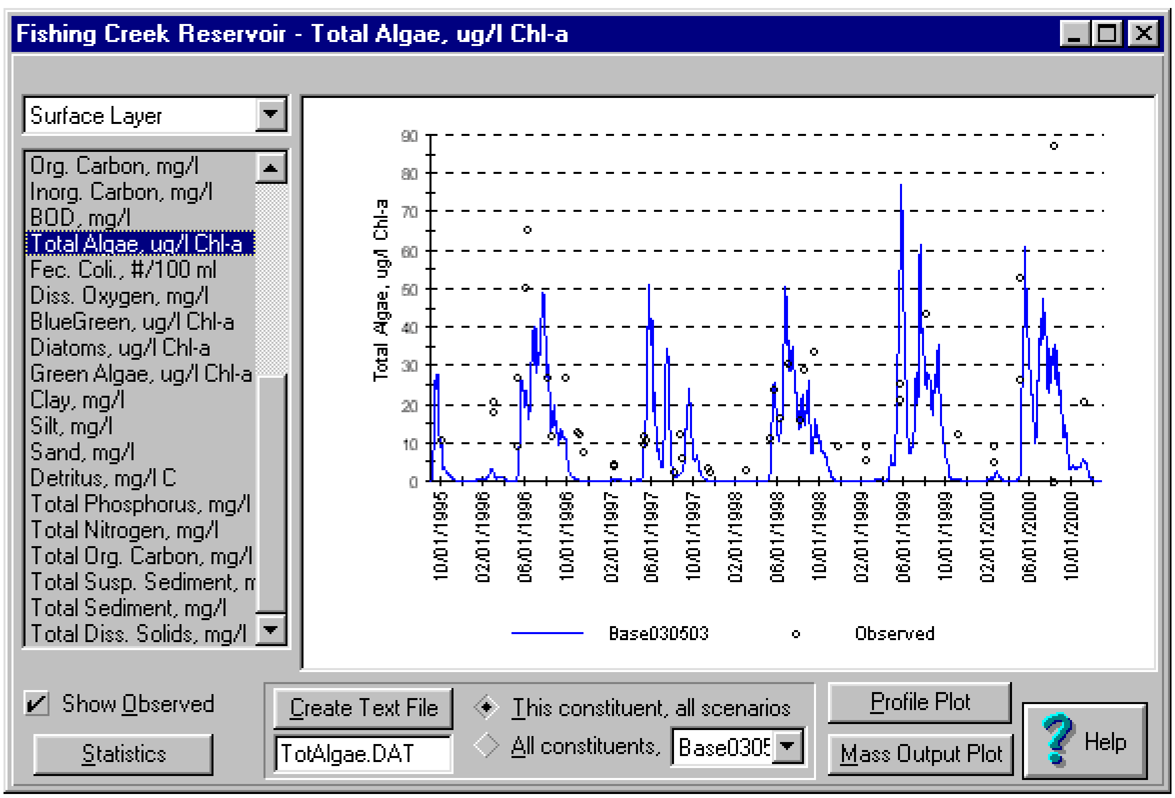


Figure 5-32
Simulated and observed total algae in Fishing Creek Reservoir.

GREAT FALLS RESERVOIR

Great Falls Reservoir is immediately downstream of Fishing Creek Reservoir. Figure 5-33 through Figure 5-38 present the simulation results for NH3, NO3, TN, PO4, TP, and total algae, respectively. The model has good match with observed nutrient and algae concentrations. The model follows the seasonal variations within the range of observed nutrient values, and the model has simulated total algae fairly accurately.

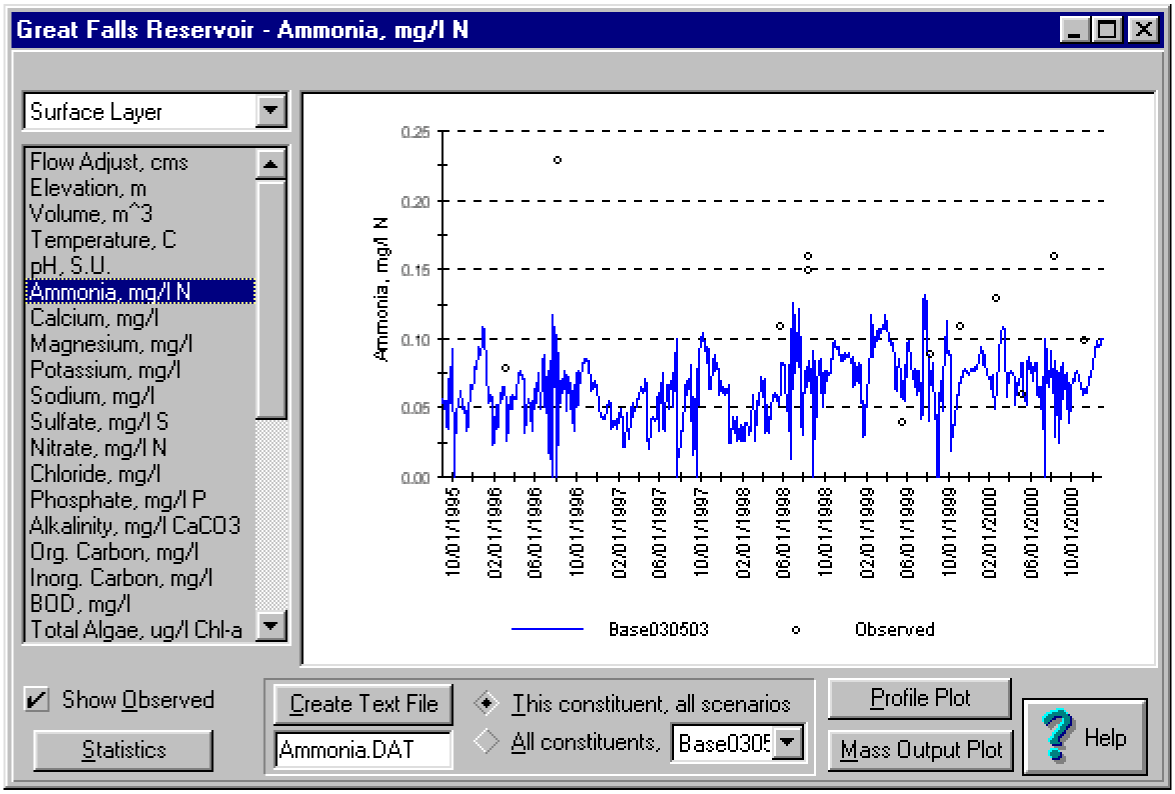


Figure 5-33
Simulated and observed NH3 in Great Falls Reservoir.

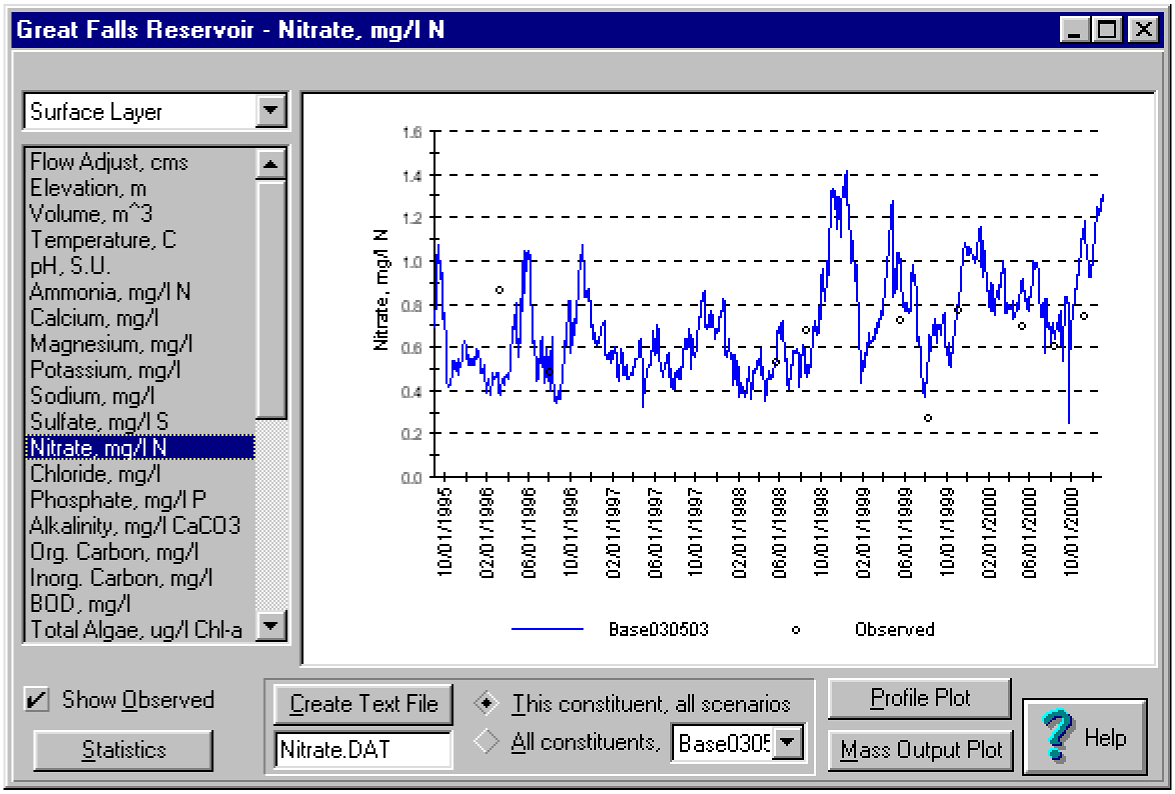


Figure 5-34
Simulated and observed NO3 in Great Falls Reservoir.

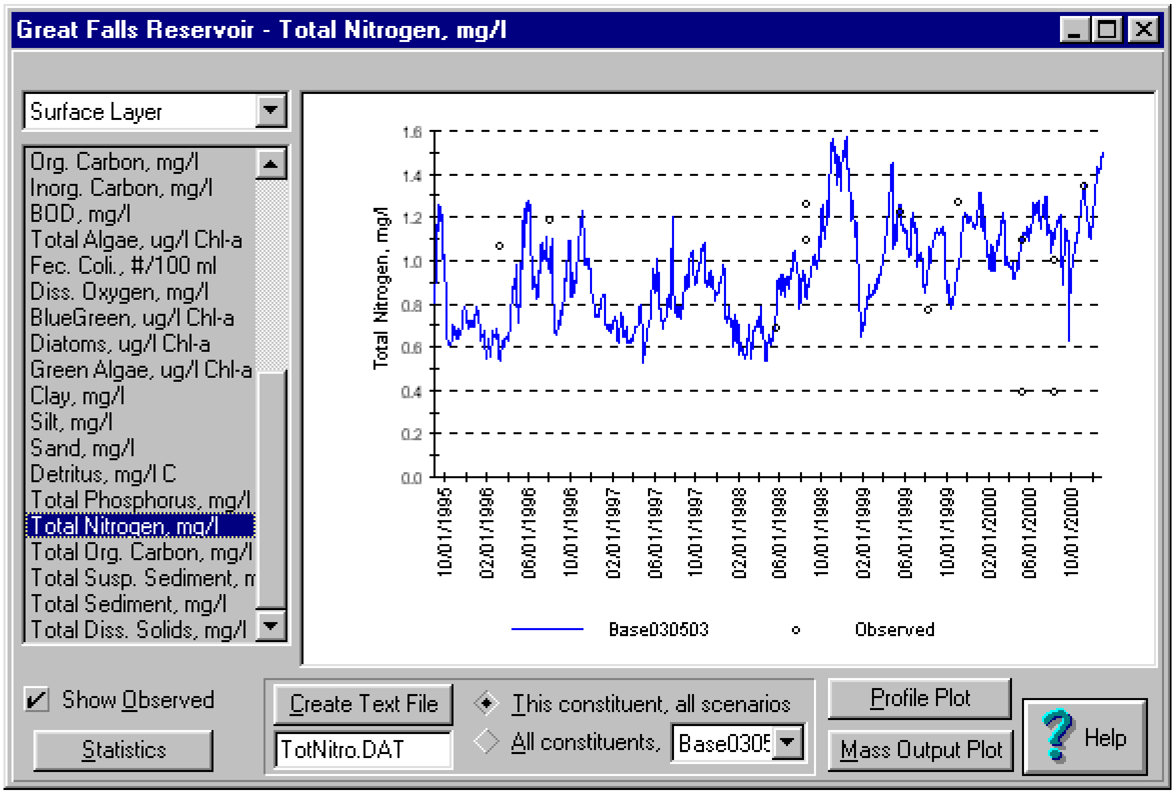


Figure 5-35
Simulated and observed TN in Great Falls Reservoir.

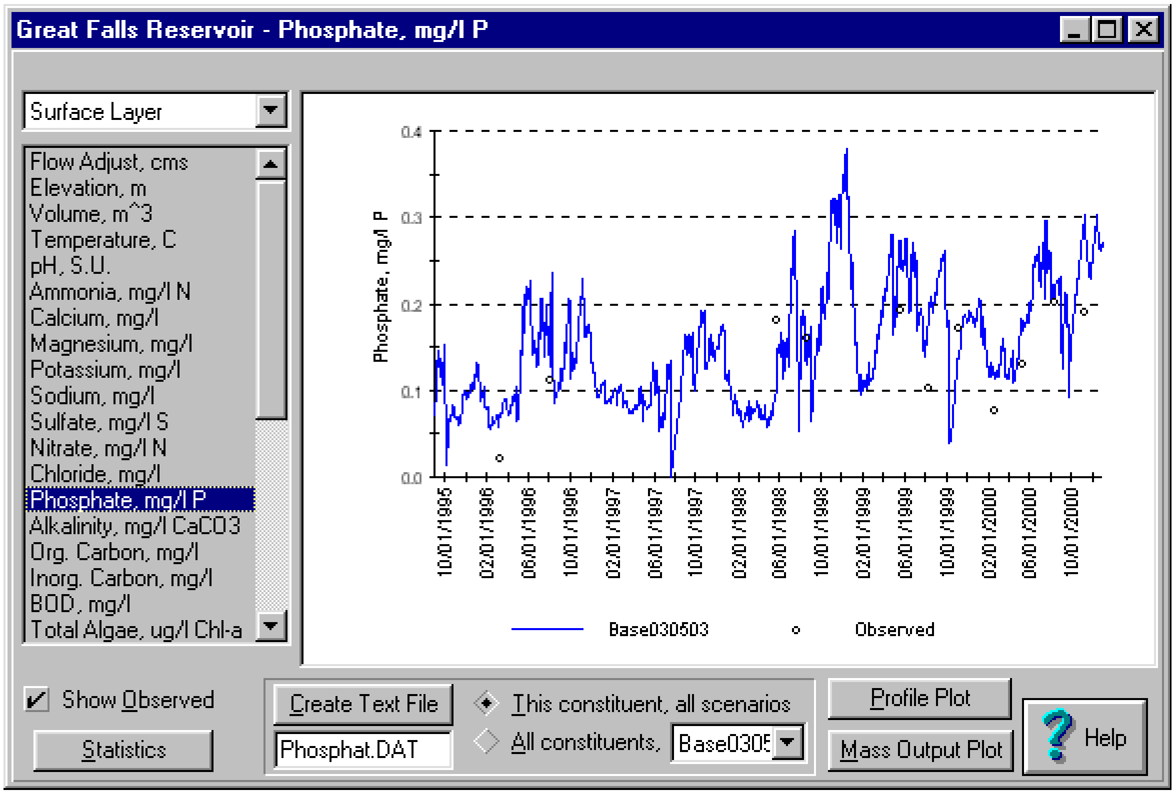


Figure 5-36
|Simulated and observed PO4 in Great Falls Reservoir.

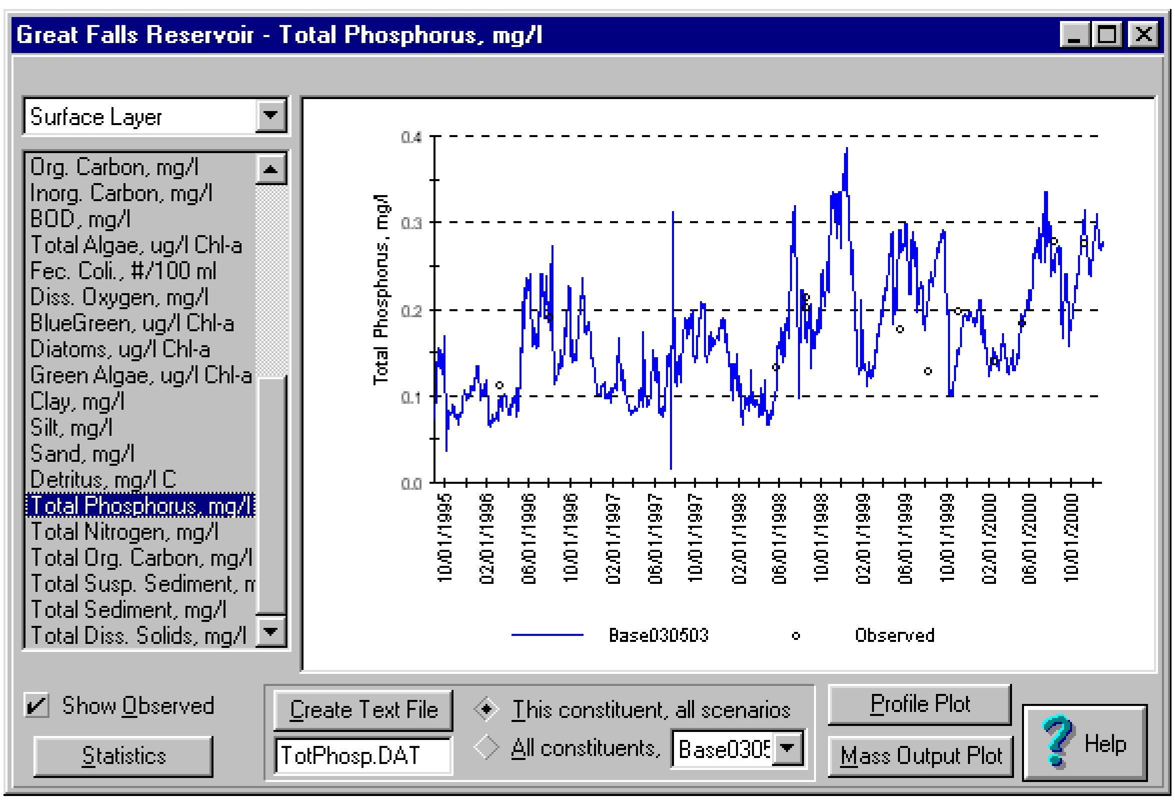


Figure 5-37
Simulated and observed TP in Great Falls Reservoir.

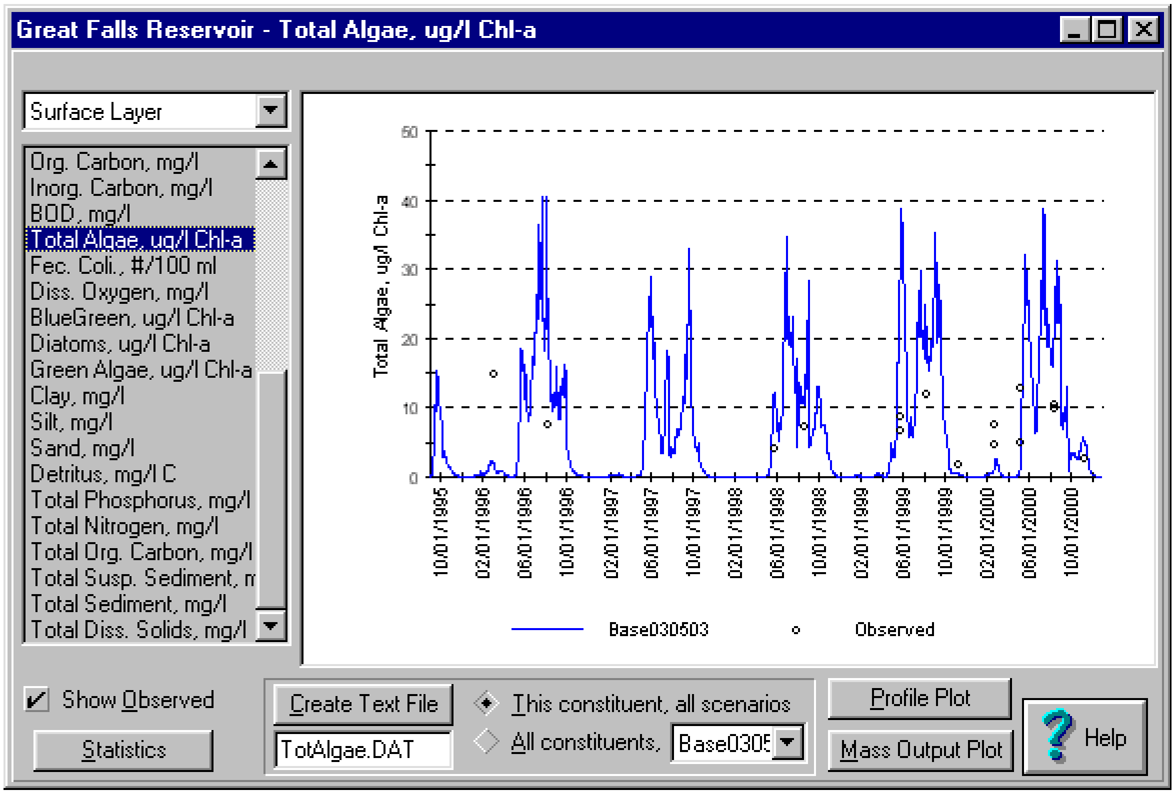


Figure 5-38
Simulated and observed total algae in Great Falls Reservoir.

CEDAR CREEK RESERVOIR

Cedar Creek Reservoir is the last of the chain reservoirs. Figure 5-39 through Figure 5-41 present the simulation results for NH3, NO3, TN, PO4, TP and total algae, respectively. Simulated nutrient and algae compare very well to their respective observed values.

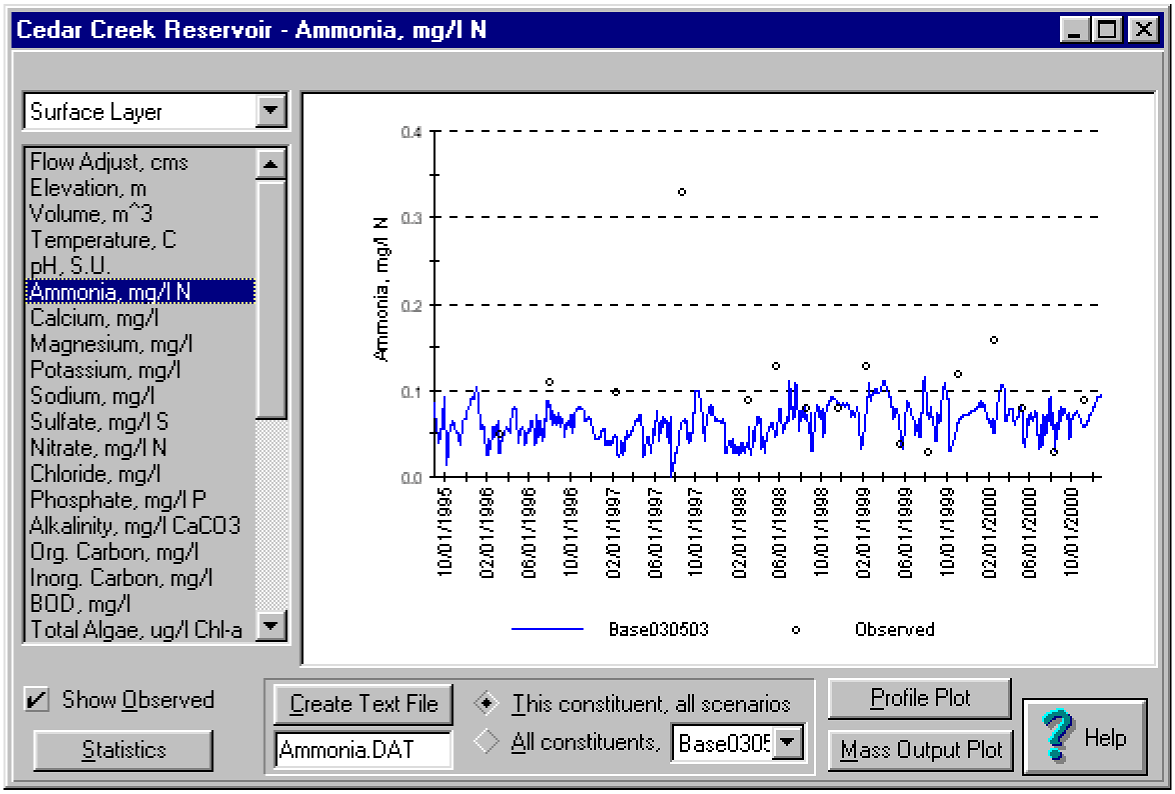


Figure 5-39
Simulated and observed NH3 in Cedar Creek Reservoir.

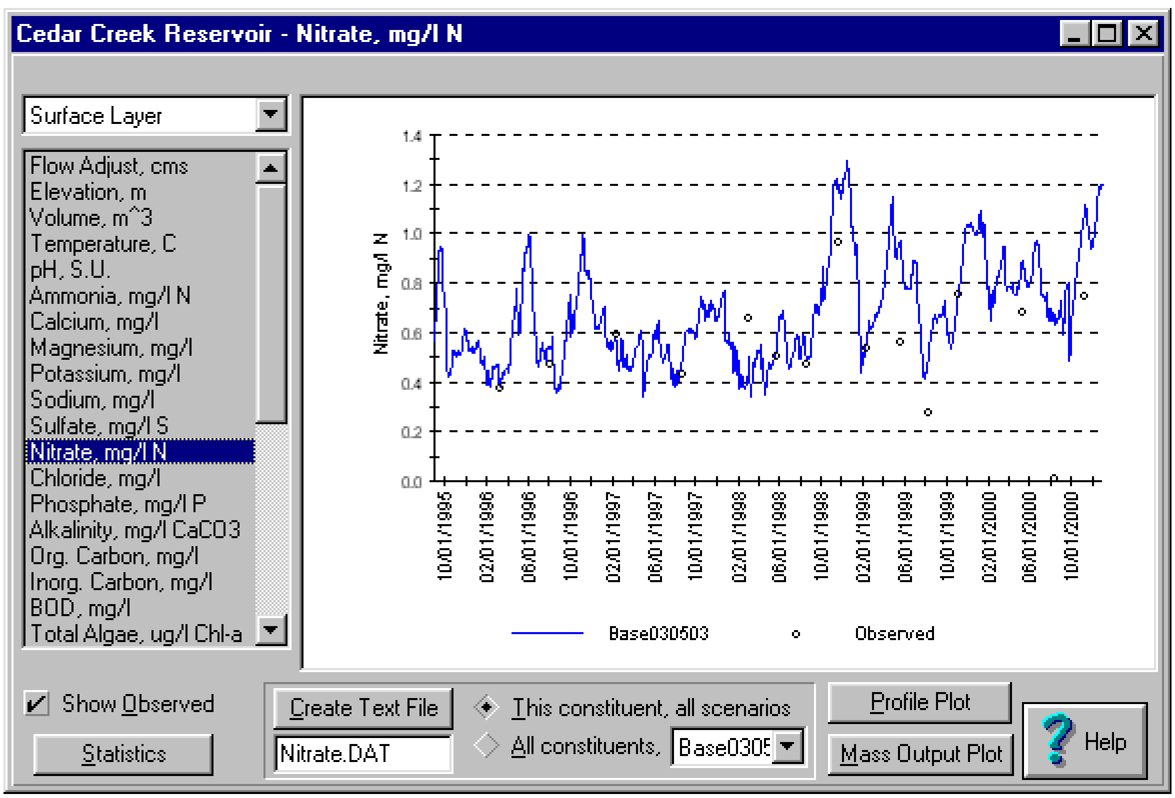


Figure 5-34
Simulated and observed NO3 in Cedar Creek Reservoir.

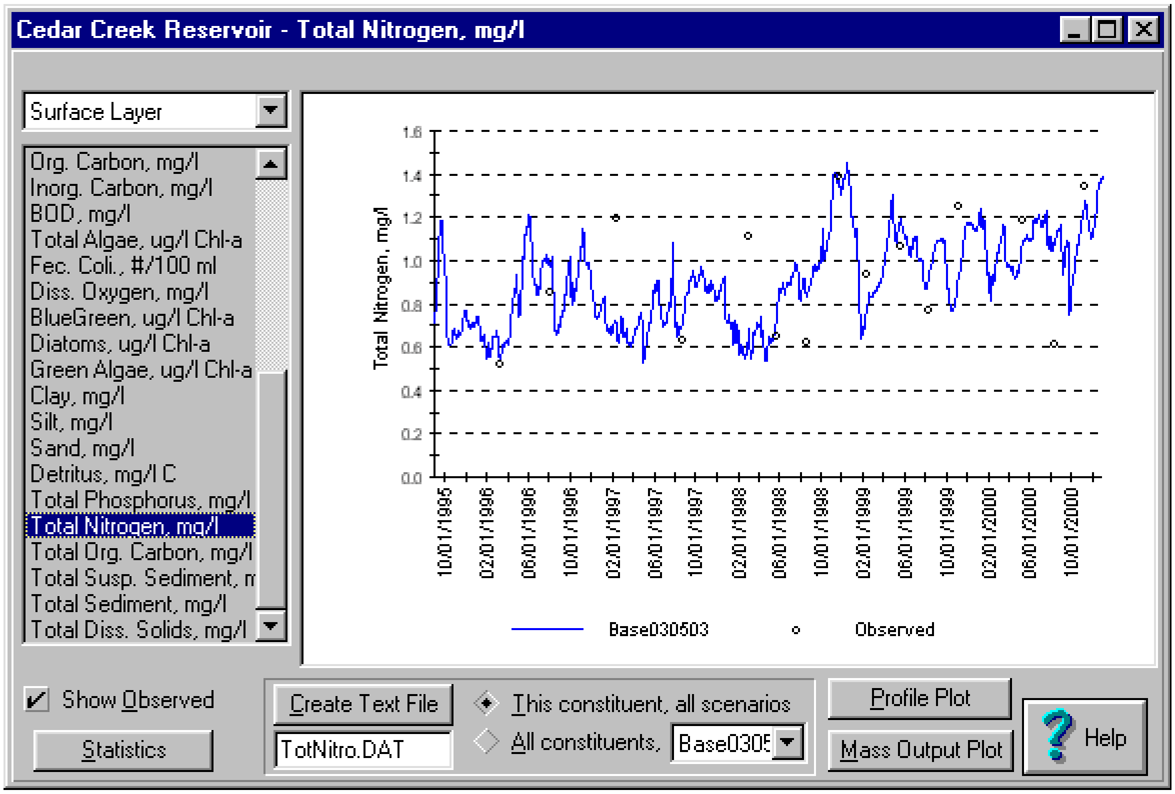


Figure 5-40
Simulated and observed TN in Cedar Creek Reservoir.

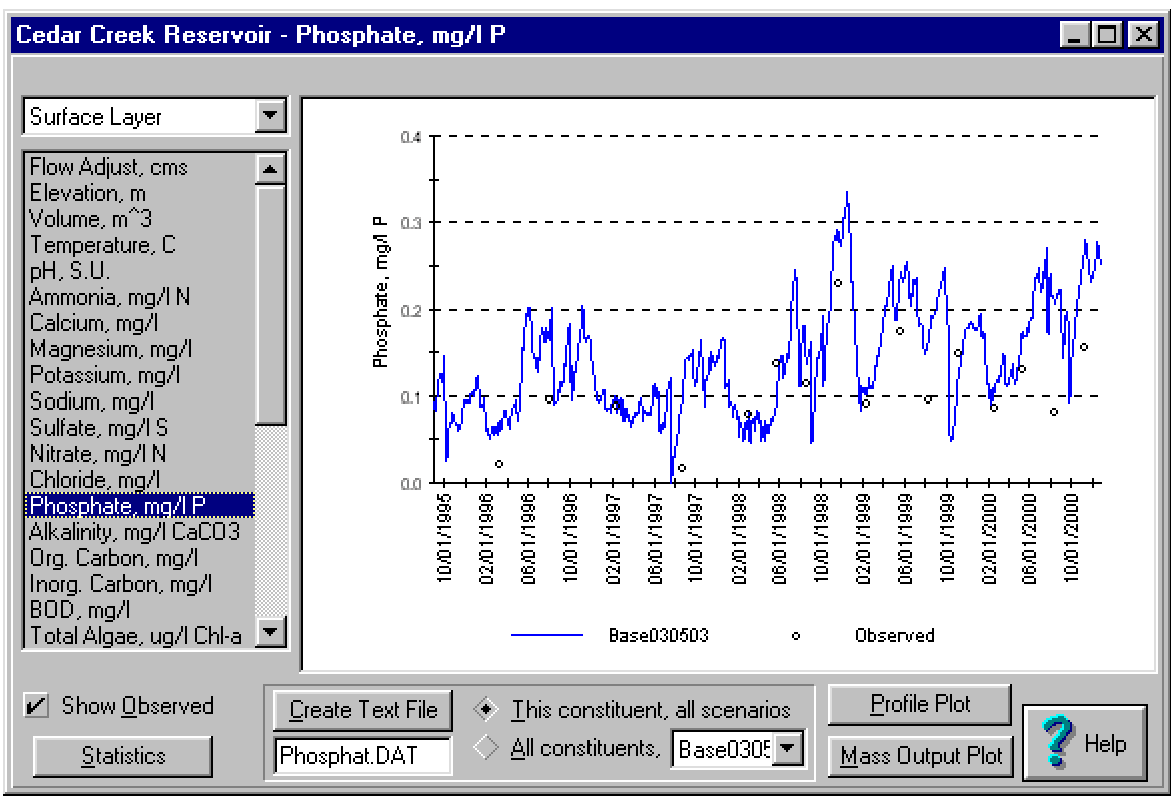


Figure 5-36
Simulated and observed PO4 in Cedar Creek Reservoir.

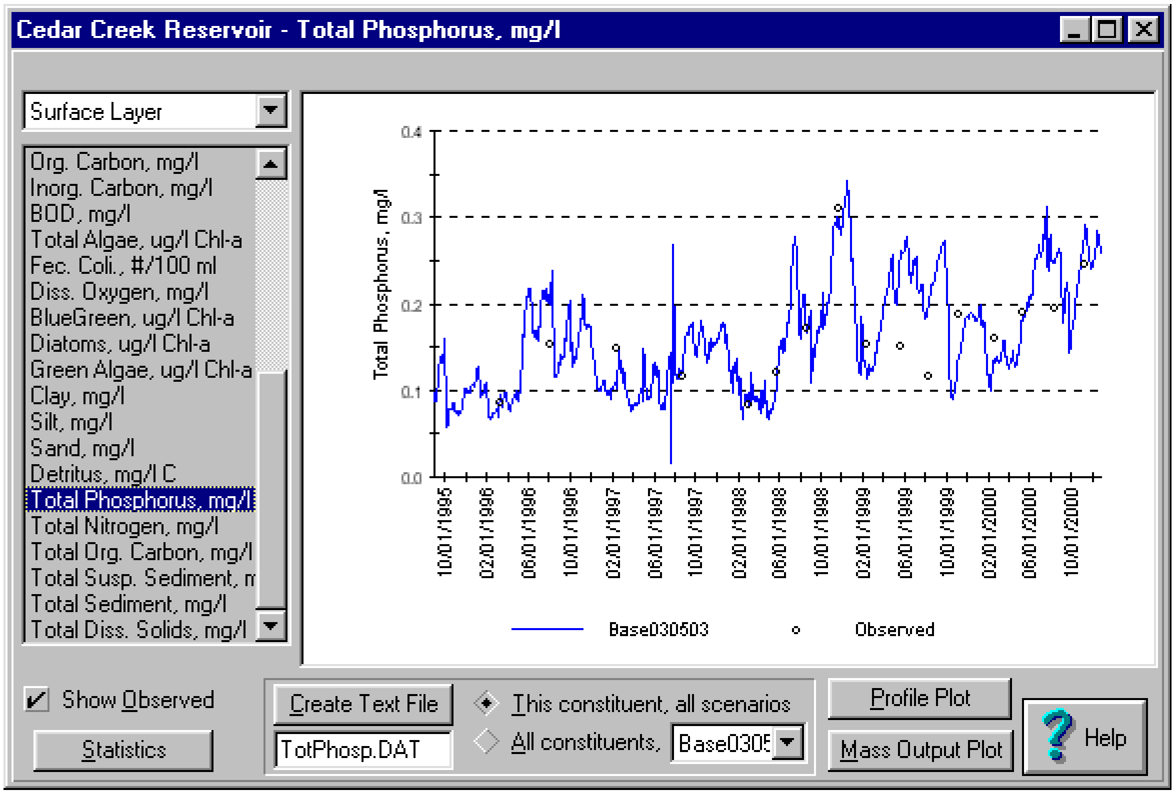


Figure 5-37
Simulated and observed TP in Cedar Creek Reservoir.

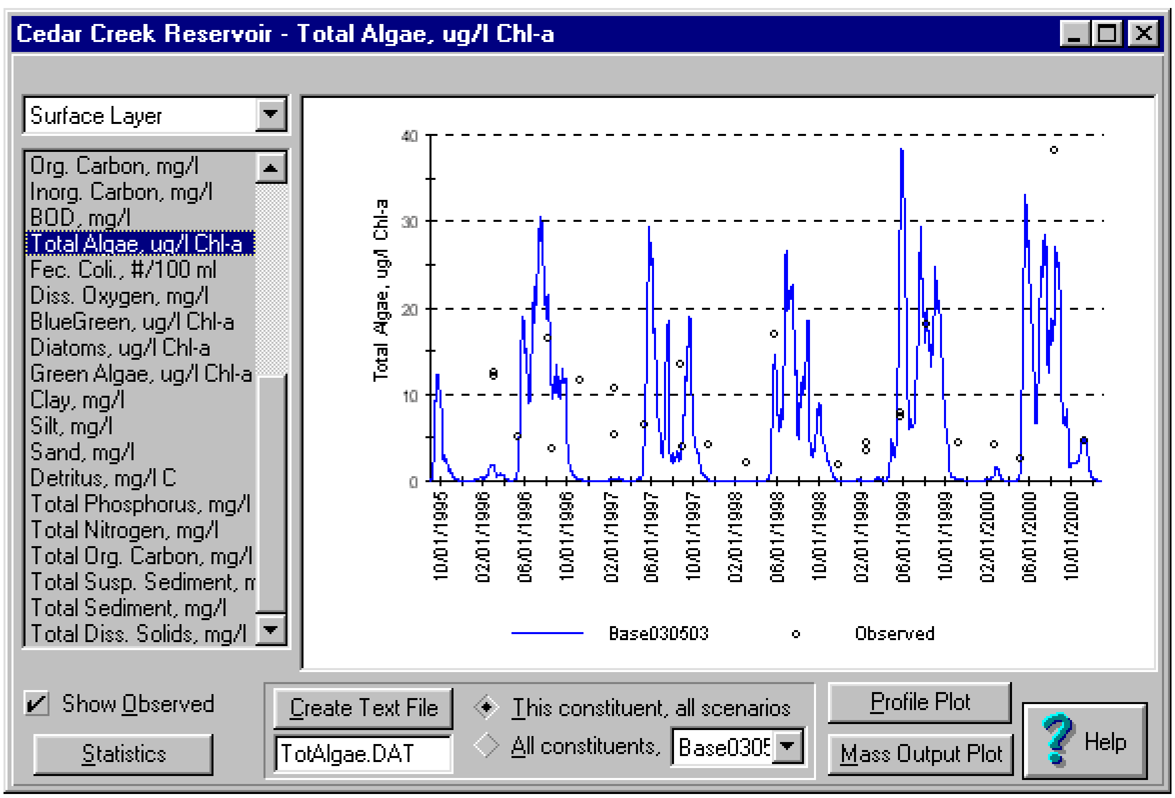


Figure 5-41
Simulated and observed total algae in Cedar Creek Reservoir.

LAKE WATEREE

Lake Wateree is the last reservoir of the Lower Catawba River. In WARMF, Lake Wateree is divided into several lake segments. Model results are compared to the measured data at segment 3, near the dam.

Figure 5-42 through Figure 5-47 compare the simulated and observed nutrients and algae at segment 3 of Lake Wateree. Simulated TN and TP concentrations are within the range of their observed values, with predicted TP at the upper end of the measured range. However, there is a fair agreement in the prediction of total algae. The model follows the observed seasonal variations, and slightly under-predicts the short diatom blooms in early spring.

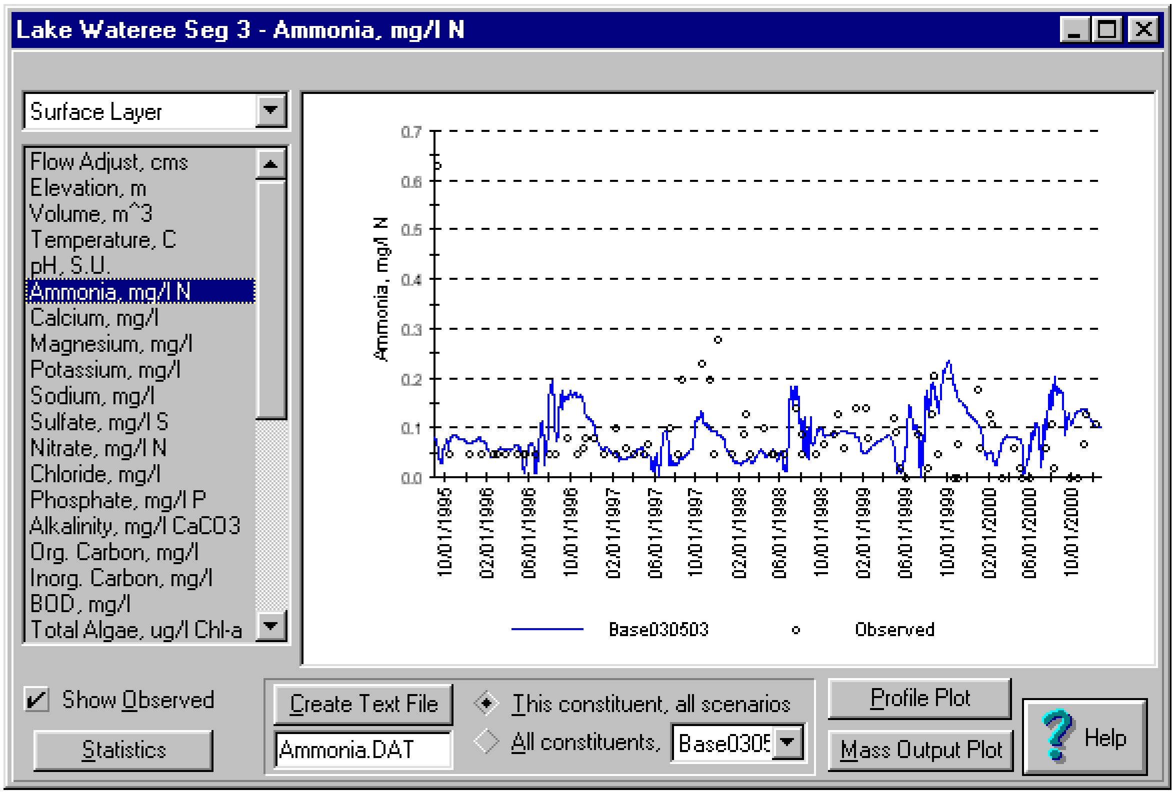


Figure 5-42
Simulated and observed NH3 in Lake Wateree.

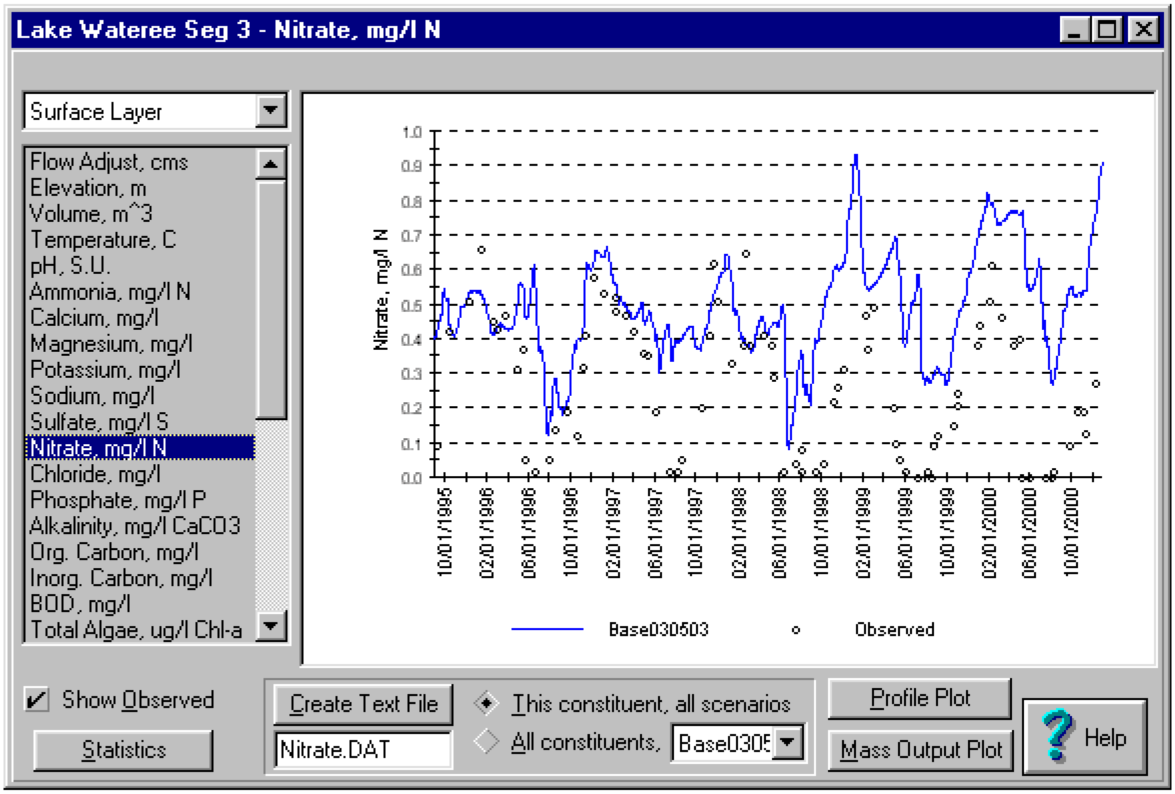


Figure 5-43
Simulated and observed NO3 in Lake Wateree.

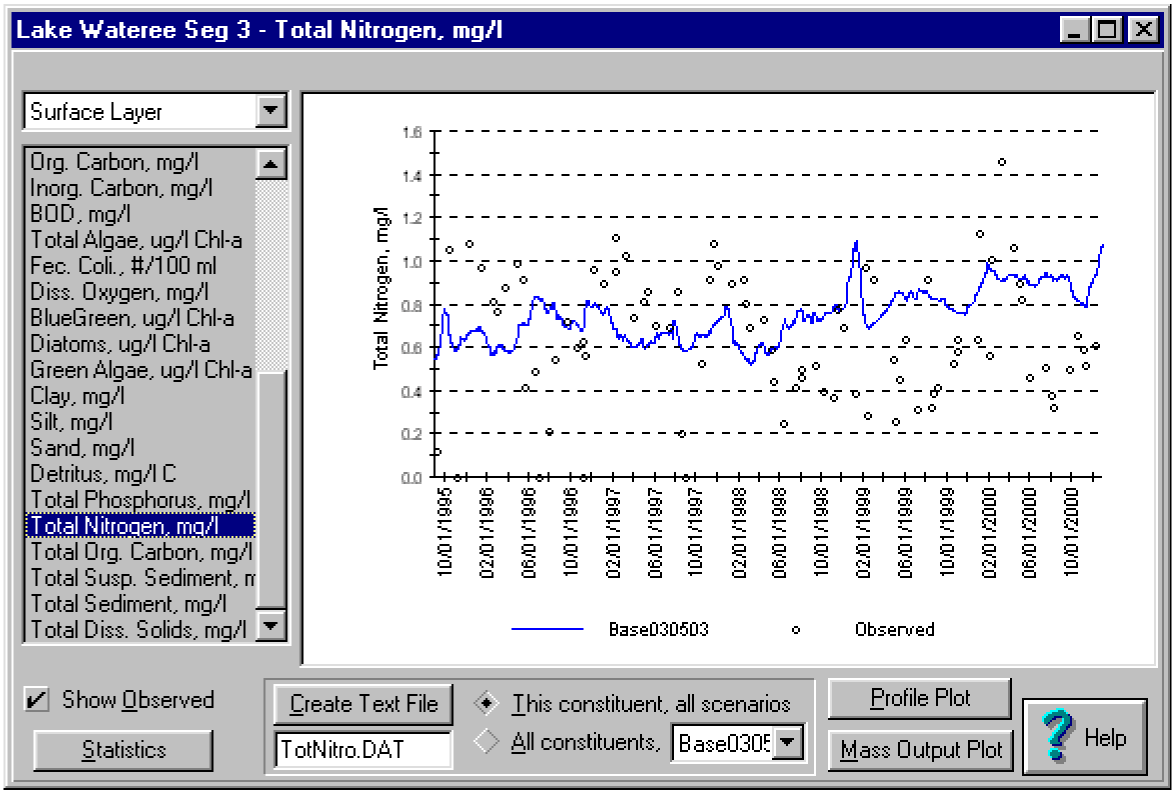


Figure 5-44
Simulated and observed TN in Lake Wateree.

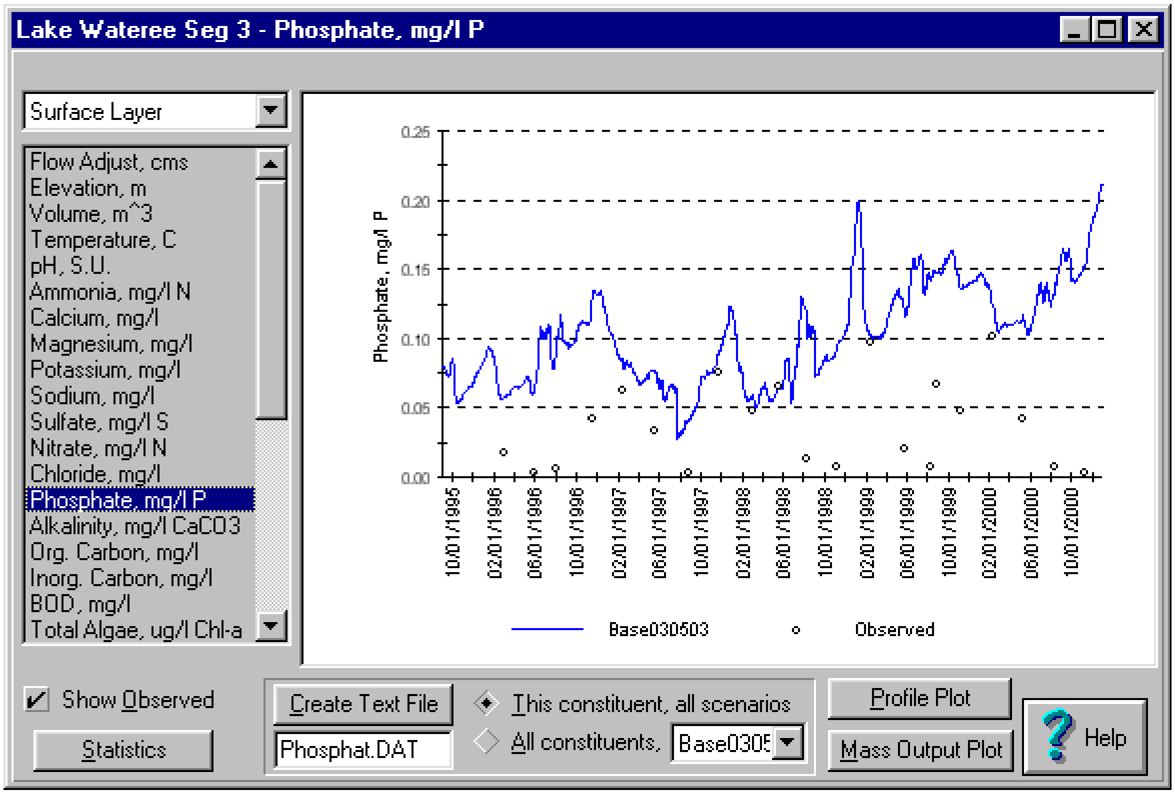


Figure 5-45
Simulated and observed PO4 in Lake Wateree.

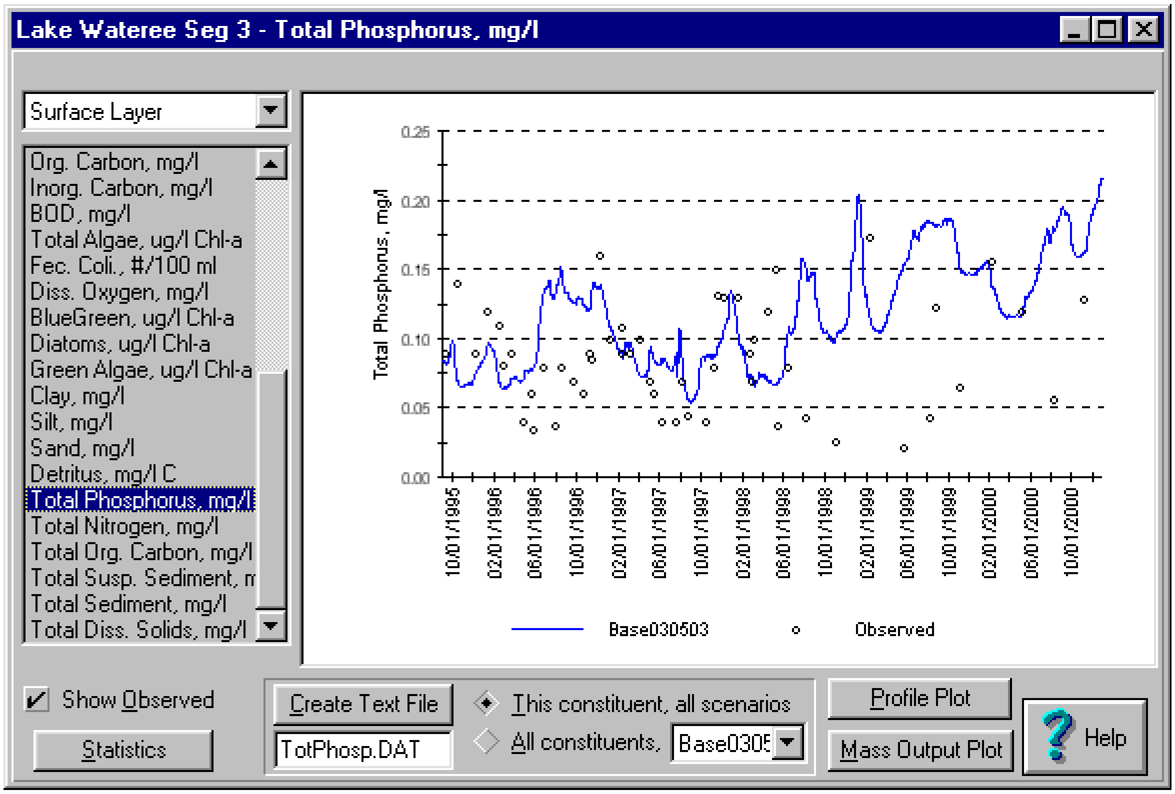


Figure 5-46
Simulated and observed TP in Lake Wateree.

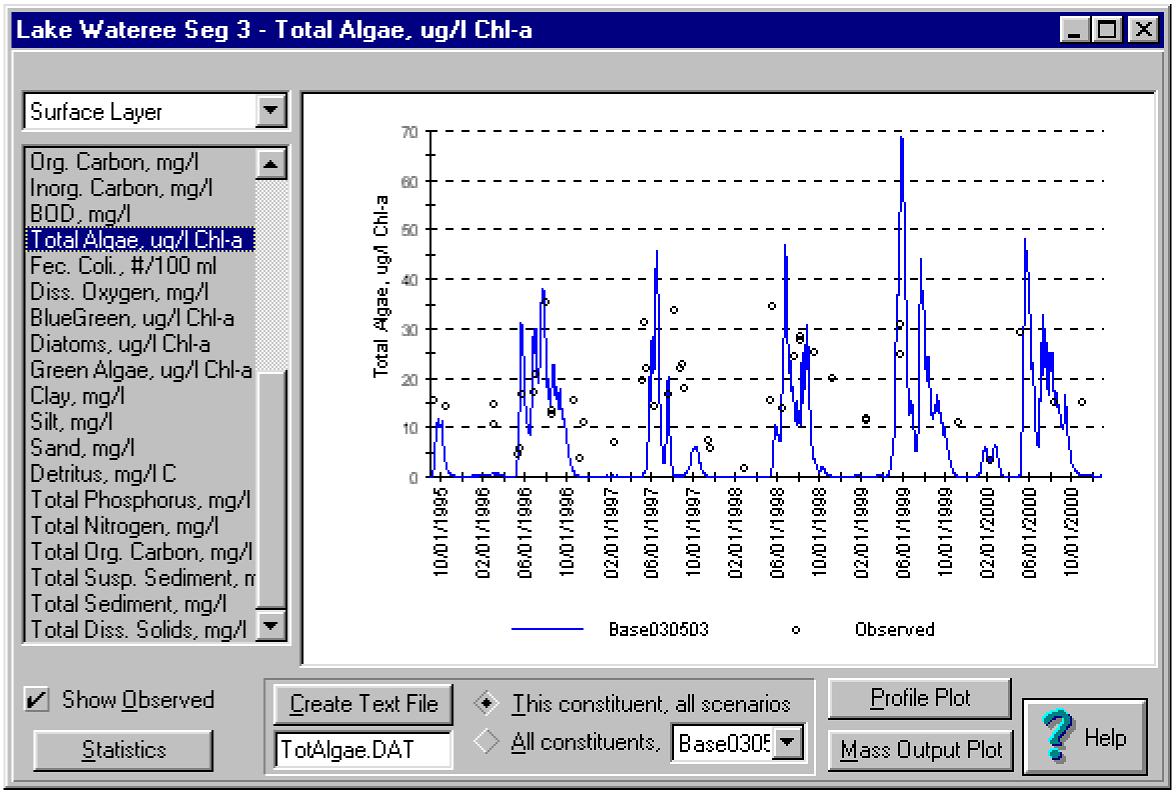


Figure 5-47
Simulated and observed total algae in Lake Wateree.

SUMMARY

Overall, the model simulates nutrient and algae concentrations in the Lower Catawba with a reasonable accuracy. The discrepancies between simulated and observed nutrients do not lead to significant error in algae concentrations in the reservoirs. The model appears to under predict the diatom bloom in early spring. Additional calibration using the newly functional lake-dependent algae coefficients may be able to better match observed algal concentrations through all seasonal blooms including the spring bloom.

6. POLLUTION LOADS

This chapter describes the model output for the point and nonpoint pollution loads from various regions of the Lower Catawba River Basin. With this knowledge, the stakeholders can determine where the pollution loads come from, what reductions scenarios can be formulated, and who are responsible parties to the water quality deterioration.

The breakdowns of regions are Fishing Creek, Sugar Creek, Fishing Creek Reservoir, and Lake Wateree. WARMF provides two types of loadings (regional loading and source contribution). The regional loading is the pollution load from the local land in each region to the stream. WARMF also output the regional loading attributable to various land use categories. The source contribution loading displays pollution loads from local source and from the upstream sources. The source loading is the product of the flow and concentration in the stream at the location of the loading bar.

FISHING CREEK

Table 6-1 shows the regional loading from Fishing Creek Sub-watershed region. The loading rate is the average rate in kilograms per day (kg/d) through the simulation period of September 1995 to December 2000. Also shown is the loading yield (area-weighted loading rate) in kilograms per hectare per year (kg/ha/yr).

In the Fishing Creek Sub-watershed, over 75% of the total TP originates from pasture lands. TN is derived from a variety of sources including pasture and cultivated lands. The deciduous and evergreen contributions of TN are also significant. The loading from forest lands is likely a result of NO3 in the form of wet deposition falling onto the large forested areas and then leaching from the soil into the stream. The contributions from forested lands seem large due to their large acreage. However, the yields of TN from forest lands are smaller than those from the other land uses, excluding water and barren land types.

Table 6-1
Nutrient loading and yield by land use in the Fishing Creek Sub-watershed.

	Loading rate, kg/d		Yield, kg/ha/yr	
Land use/source	TP	TN	TP	TN
Groundwater Pumping	0.0	0		
Deciduous Forest	0.64	59.0	0.01	1.22
Evergreen Forest	0.74	62.7	0.01	1.21
Mixed Forest	0.52	36.7	0.02	1.23
Pasture	52.8	109.0	1.79	3.70
Cultivated	7.60	44.0	0.30	1.74
Recreation. Grasses	0.19	2.1	0.14	2.30
Water	0.01	1.5	0.01	1.11
Barren	0.01	1.6	0.01	1.13

Low Intensity Develop.	0.73	8.2	0.12	1.34
High Intensity Develop.	0.29	3.5	0.16	1.92
Comm / Industrial	0.61	6.2	0.19	1.93
Wetlands	0	0	0	0
Point Sources	4.0	50.2	-	-
TOTAL	68.2	385	-	-

SUGAR CREEK

In the Sugar Creek Sub-watershed point sources contribute the overwhelming majority of TP and TN (Table 6-2). Approximately 97% of TP loading and 90% of TN loading originate from point sources. A few large wastewater treatment plants of Mecklenburg County in the Charlotte area are responsible for the bulk of these point source loads.

Although lower in comparison to the point source loads, the non-point loads from developed land uses (low and high intensity development, and commercial/industrial) are relatively high in the region. For example, the TP load from developed lands in the Fishing Creek region is 1.3 kg/d, as compared to a total of 7.7 kg/d. The greatly urbanized lands in Mecklenburg County generate a relatively significant level of nonpoint loads of nutrients to Sugar Creek.

Table 6-2
Nutrient loading and yield by land use in the Sugar Creek Sub-watershed.

	Loading rate, kg/d		Yield, kg/ha/yr	
Land use/source	TP	TN	TP	TN
Groundwater Pumping	0	0		
Deciduous Forest	0.80	39.9	0.03	1.47
Evergreen Forest	0.78	47.7	0.02	1.39
Mixed Forest	0.46	24.4	0.03	1.44
Pasture	6.44	33.0	0.77	3.92
Cultivated	1.16	20.6	0.11	1.97
Recreation Grasses	0.86	14.5	0.15	2.48
Water	0.03	1.2	0.03	1.15
Barren	0.06	3.2	0.02	1.15
Low Intensity Develop.	3.65	59.3	0.09	1.44
High Intensity Develop.	3.09	38.1	0.15	1.86
Comm / Industrial	3.26	49.4	0.16	2.39
Wetlands	0	0	0	0
Point Sources	800	2530	-	-
TOTAL	821	2860	-	-

FISHING CREEK RESERVOIR

Local pollution loads to Fishing Creek Reservoir including Cane Creek are presented in Table 6-3. The loading does not reflect contributions from the Catawba River section above Cane Creek. The single highest contributor of TP is pasture lands. Pastures contribute about 70% of the total load. Most of the TN load is from agricultural lands and from forested lands. TN in the air and in the rainfall are deposited onto a very large acreage of the forested lands. This TN eventually leaches from the soil and reaches the streams and reservoir.

Table 6-3
Nutrient loading and yield by land use/source to Fishing Creek Reservoir.

	Loading rate, kg/d		Yield, kg/ha/yr	
Land use/source	TP	TN	TP	TN
Groundwater Pumping	0	0		
Deciduous Forest	4.08	44.4	0.10	1.13
Evergreen Forest	4.76	26.4	0.19	1.05
Mixed Forest	2.30	17.5	0.15	1.11
Pasture	73.8	36.4	8.08	3.99
Cultivated	9.72	30.8	0.46	1.45
Recreational Grasses	0.54	1.1	0.93	1.80
Water	0.95	2.9	0.38	1.19
Barren	0.11	1.6	0.06	0.89
Low Intensity Develop.	1.66	8.7	0.26	1.33
High Intensity Develop.	0.25	1.9	0.27	1.79
Comm / Industrial	0.95	5.7	0.37	2.04
Wetlands	0	0	0	0
Direct Precipitation	0	10.6	-	-
Direct Dry Deposition	0	0.501	-	-
General Point Sources	5.36	9.26	-	-
TOTAL	104	198		-

LAKE WATEREE

Pollution loads and yields from the region adjacent to Lake Wateree are given in Table 6-4. The agriculture lands contribute roughly 75% of TP. Over 65% of the TN load originates from NO3 and NH3 in rainfall (direct precipitation land use) that leaches through the soil of forested lands into the streams and lake.

Table 6-4
Nutrient loading and yield by land use/source in the Lake Wateree Subwatershed.

Land use/source	Loading rate, kg/d TP	Loading rate, kg/d TN	Yield, kg/ha/yr TP	Yield, kg/ha/yr TN
Groundwater Pumping	0	0		
Deciduous Forest	12.4	92.0	0.16	1.21
Evergreen Forest	18.8	125.0	0.18	1.17
Mixed Forest	8.7	38.8	0.28	1.25
Pasture	29.9	11.9	13.00	5.20
Cultivated	77.5	16.4	11.20	2.37
Recreational Grasses	0.1	0.1	3.38	1.90
Water	0.2	3.6	0.04	0.91
Barren	0.8	27.0	0.03	0.98
Low Intensity Develop.	0.2	1.1	0.23	1.10
High Intensity Develop.	0.0	0.0	0.19	1.53
Comm / Industrial	0.2	1.2	0.34	1.88
Direct Precipitation	0	67.6	-	-
Direct Dry Deposition	0	2.7	-	-
General Point Sources	0.1	3.5	-	-
TOTAL	149	391	-	-

Source Contributions

WARMF displays source contribution loading when the *Source Contribution* button is selected from the *Loading* dialog box Figure 6-1. TP and TN from upstream sources are shown for Fishing Creek Reservoir and Lake Wateree in Figure 6-1 and Figure 6-2. Of the two bar charts in each figure, the bar on the left corresponds to the Fishing Creek Reservoir, and the bar on the right corresponds to Lake Wateree.

Figure 6-1 shows the source contributions of TP loads to Fishing Creek Reservoir and Lake Wateree. The bar chart has three sections: the light blue at the bottom represents the pollution source contribution originating upstream; the green portion in the middle represents pollution from local or regional nonpoint sources; and the magenta on the top is for local point sources.

The TP load to Fishing Creek Reservoir is 1,620 kg/d. The largest contributor to this load comes from point source discharges to Sugar Creek, which drains to the Fishing Creek Reservoir (60%). Upstream source from Lake Wylie and above provides 18% of the load. The local nonpoint source load contributes about 22% of total load.

The TP load to Lake Wateree is 1,430 kg/d. As shown, nearly all the TP load to Lake Wateree originates from the upstream source. Local regional load comprises less than 1% of the total load.

By comparing the TP load to Fishing Creek (1,620 kg/d) to the TP load to Lake Wateree (1,430 kg/d), we can get an idea of the magnitude of TP that is being assimilated in Great Falls and

Cedar Creek Reservoirs. If no assimilation were occurring, these values would be roughly similar, assuming there are no significant TP inputs to either of the reservoirs. At least 12% of the TP load to Fishing Creek Reservoir does not reach the lower lake because of assimilation.

Figure 6-2 shows the source contribution of TN loads to Fishing Creek Reservoir and Lake Wateree. The TN load to the Fishing Creek Reservoir is 8,390 kg/d. About 46% of this load is contributed by point source load to Sugar Creek, which drains to Fishing Creek Reservoir. About 43% of the load is derived from Lake Wylie and above. The TN load to Lake Wateree is 8,460 kg/d. Nearly all TN load to Lake Wateree is from upstream source.

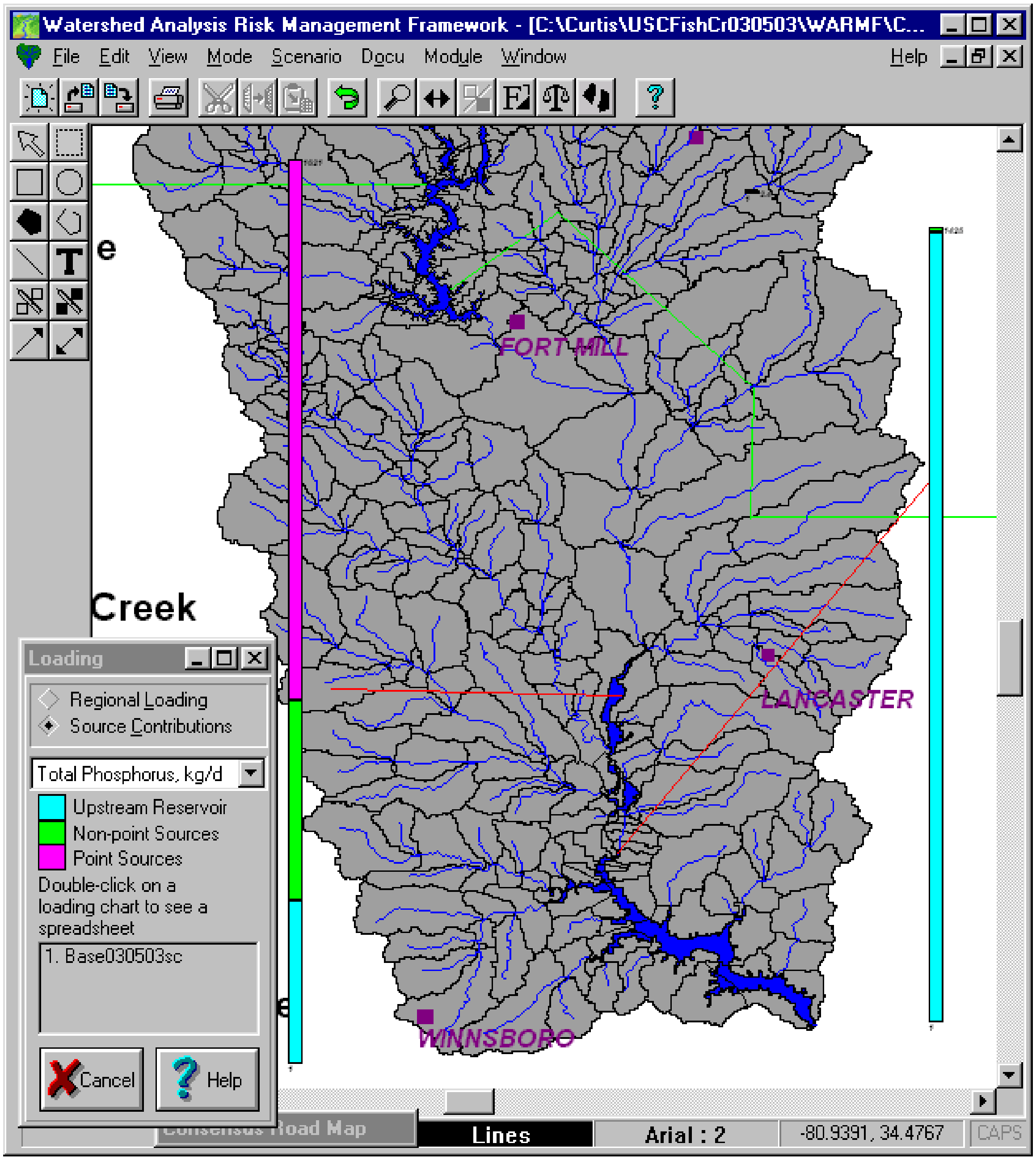


Figure 6-1
Source contributions of TP to Fishing Creek Reservoir and Lake Wateree.

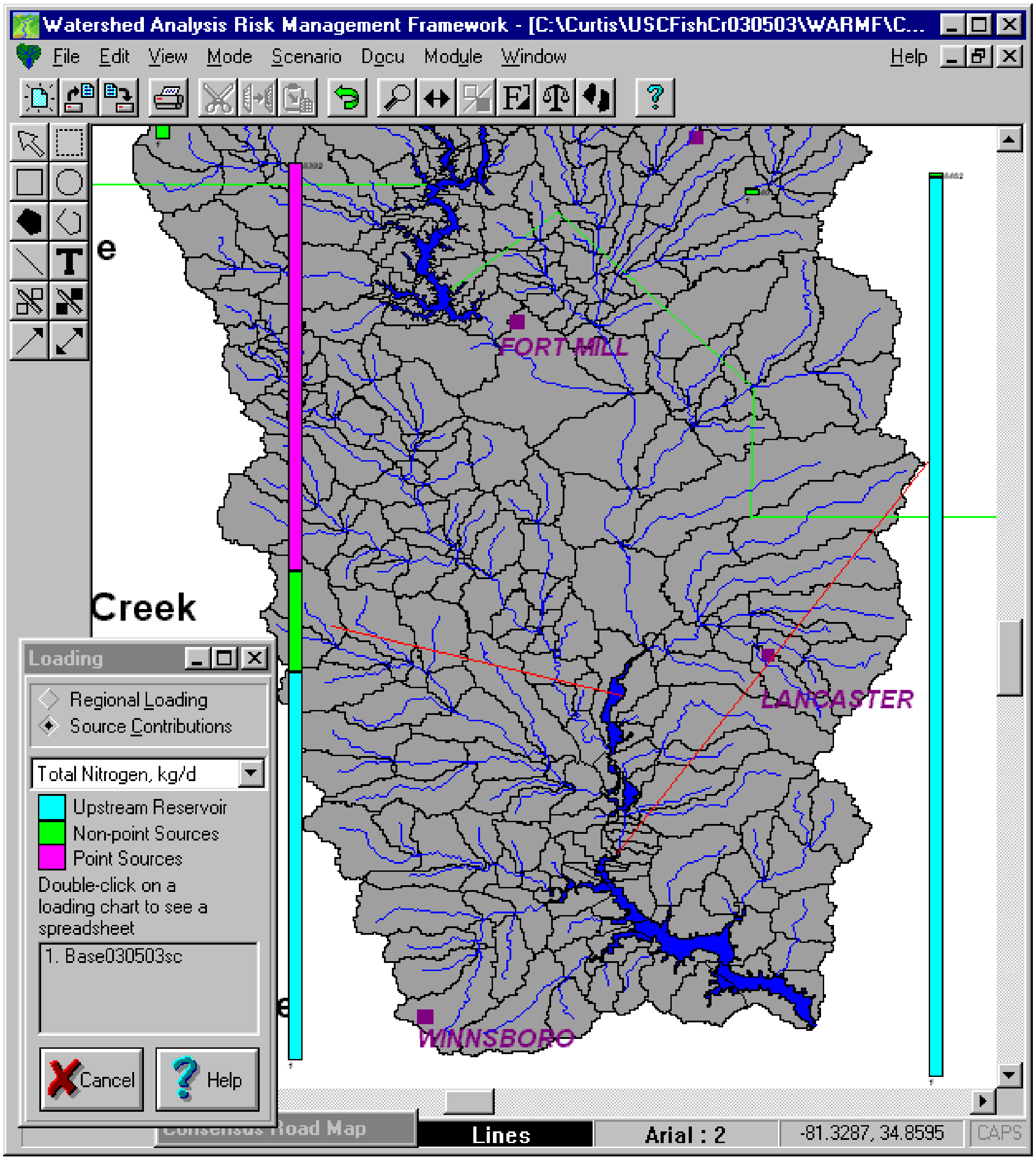


Figure 6-2
Source contributions of TN to Fishing Creek Reservoir and Lake Wateree.

SUMMARY

Three sewage treatment plants of Mecklenburg County, North Carolina contribute major point source loads of phosphate, ammonia, and nitrate to Sugar Creek, which drains into Fishing Creek Reservoir. Large forest lands accept atmospheric deposition of ammonia and nitrate, which eventually leach out to surface waters. The TP load to Fishing Creek Reservoir is 1,620 kg/d, 60% from point source, 18% from upstream. The TP load to Lake Wateree is 1,430 kg/d, all from upstream. The TN load to Fishing Creek Reservoir is 8,390 kg/d, 46% point source and 43% from upstream. The TN load to Lake Wateree is 8,460 kg/d, all from upstream sources.

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